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THE GEOLOGY OF THE SKI-LODGE ROAD MAP-AREA,
JASPER, ALBERTA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

by

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EDMONTON, ALBERTA

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ABSTRACT

The strata of the Ski-Lodge Road map-area, near the town of Jasper, Alberta, belong to Walcott's Miette formation. These strata, which consist of lenticular, interbedded arenaceous and argillaceous units up to 300 feet thick, are probably Precambrian in age, and correlate lithologically, if not temporally, with the Hector formation of the Bow Valley and the Horsethief Creek formation of southeastern British Columbia. Graded bedding and cross-stratification are particularly common in the arenaceous units, which also contain load-casts, flow-casts, penecontemporaneous folds, and ripple marks. Heavy mineral studies of fine-grained sandstones show that only the ultra-stable suite of zircon, tourmaline, apatite, and rutile, is present.

The conglomerates and sandstones of the arenaceous units have a composition similar to Pettijohn's feldspathic graywacke, are composed of poorly sorted and angular grains of quartz and feldspar, mica, patchy carbonate cement, and a recrystallized matrix of chlorite and muscovite. Some pebbles are composed of chess-board twinned feldspar. Argillite-fragments are common and sometimes form intraformational argillite-fragment conglomerates. Authigenic pyrite cubes in various stages of weathering are scattered throughout the arenaceous units. The argillaceous units consist of thinly bedded and laminated argillite composed of muscovite, chlorite, and silt- to fine-sand sized quartz.

The mineralogy and texture of the rocks suggest a close, topographically high source consisting of igneous and metamorphic rocks. Deposition was probably rapid in a subsiding deltaic area, with the arenaceous rocks representing the top-set beds, and the argillaceous rocks representing fore-set beds and interdistributary deposits. Cross-stratification studies indicate that the source of the sediments was to the northeast, possibly within the Canadian Shield.

Structural deformation probably occurred during the Laramide orogeny and is reflected by folding, fracturing, and metamorphism of the rocks. Eleven joint-sets, most of which are often vein-filled, have been recognized in the arenaceous units. The rocks and the vein material, though having different mineral assemblages, are within the quartz-albite-muscovite-chlorite subfacies of the greenschist metamorphic facies.

ACKNOWLEDGMENTS

With sincere gratitude this writer acknowledges the guidance and assistance given by Dr. H.A.K. Charlesworth under whose direction this study was undertaken. Grateful appreciation is extended to all members of the Department of Geology and especially to Dr. J.F. Lerbekmo for critical appraisal of the manuscript. Special acknowledgments are due to Dr. K.A.W. Crook of the Australian National University and Dr. B. Mellon of the Research Council of Alberta for their suggestions and constructive criticism, and to the Research Council of Alberta who sponsored the field work. The study was made possible by a generous fellowship from the California Standard Company. Mr. J.R.B. Coleman, Director of the National Parks Branch of the Department of Northern Affairs and National Resources of Canada, kindly permitted the sampling of rocks within Jasper National Park.

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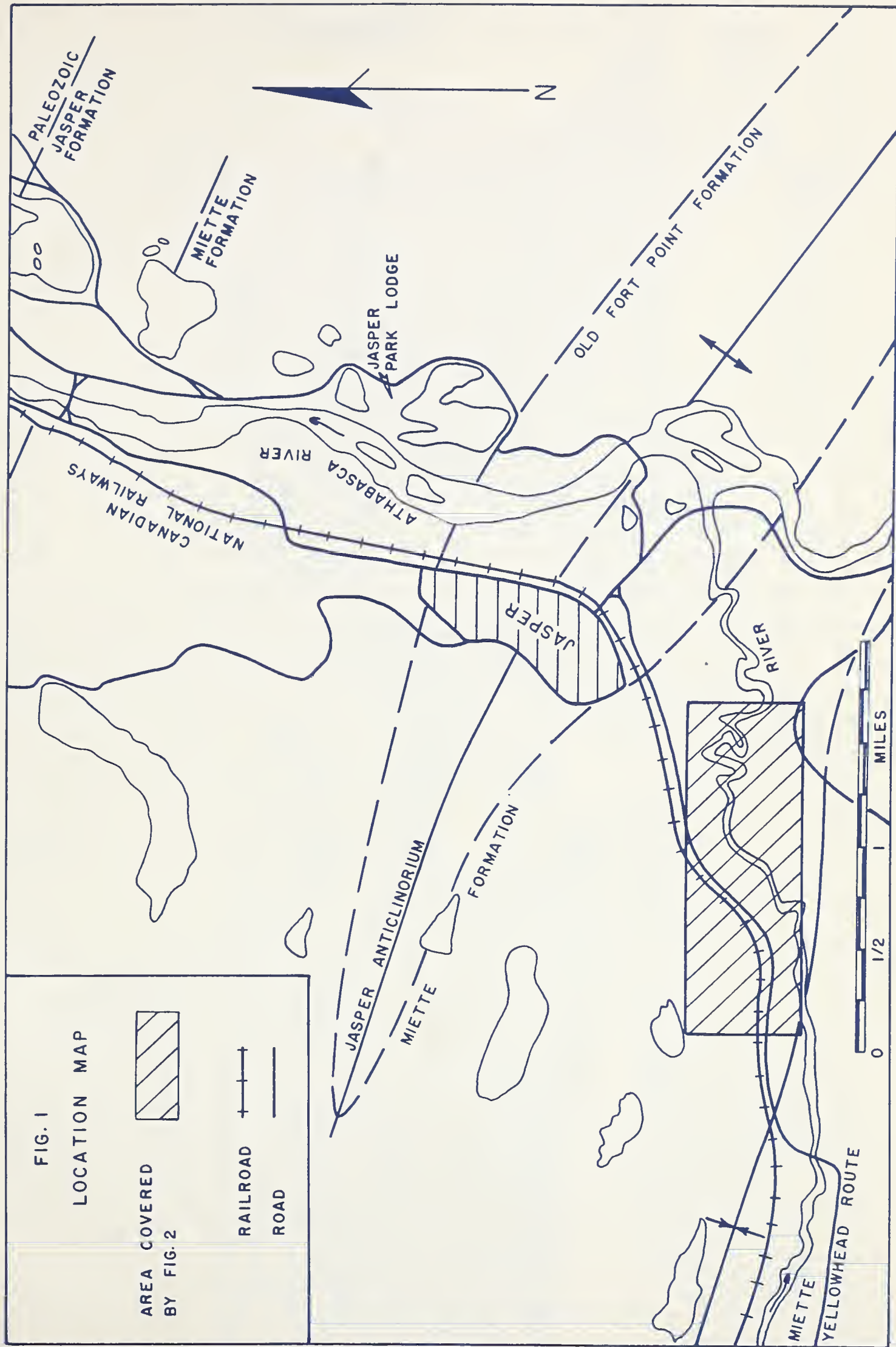
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INTRODUCTION

The Canadian Rocky Mountains, at the latitude of Jasper, can be divided into three ranges: the Foothills, consisting mainly of Mesozoic rocks; the Eastern Ranges, consisting mainly of Upper Paleozoic rocks; and the Main Ranges, consisting mainly of Lower Paleozoic and Upper Precambrian rocks. A small area approximately 1 1/2 miles southwest of Jasper, Alberta, in the Main Ranges (figs. 1 and 2) was mapped in considerable detail. This area, defined here as the Ski-Lodge Road map-area, is underlain by Precambrian strata belonging to Walcott's Miette formation (1913, p. 340).

Field mapping was carried out during the spring and fall of 1960 using aerial photographs enlarged to 4.5 inches to the mile as base maps.

Previous work has been done on the Miette formation by McEvoy (1898), Walcott (1913), Allan, Warren, and Rutherford (1932), Charlesworth and Remington (1960), and Remington (1960).



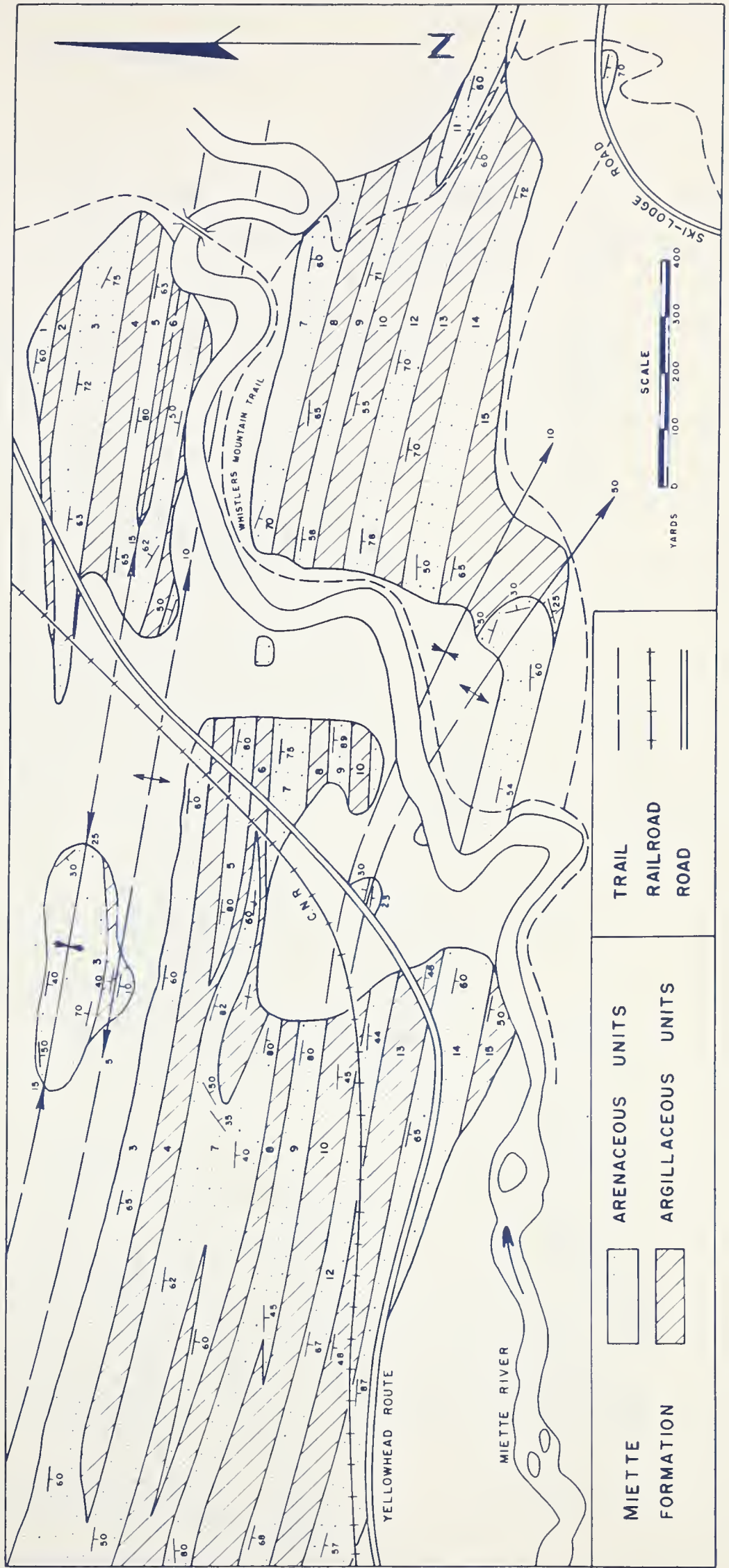
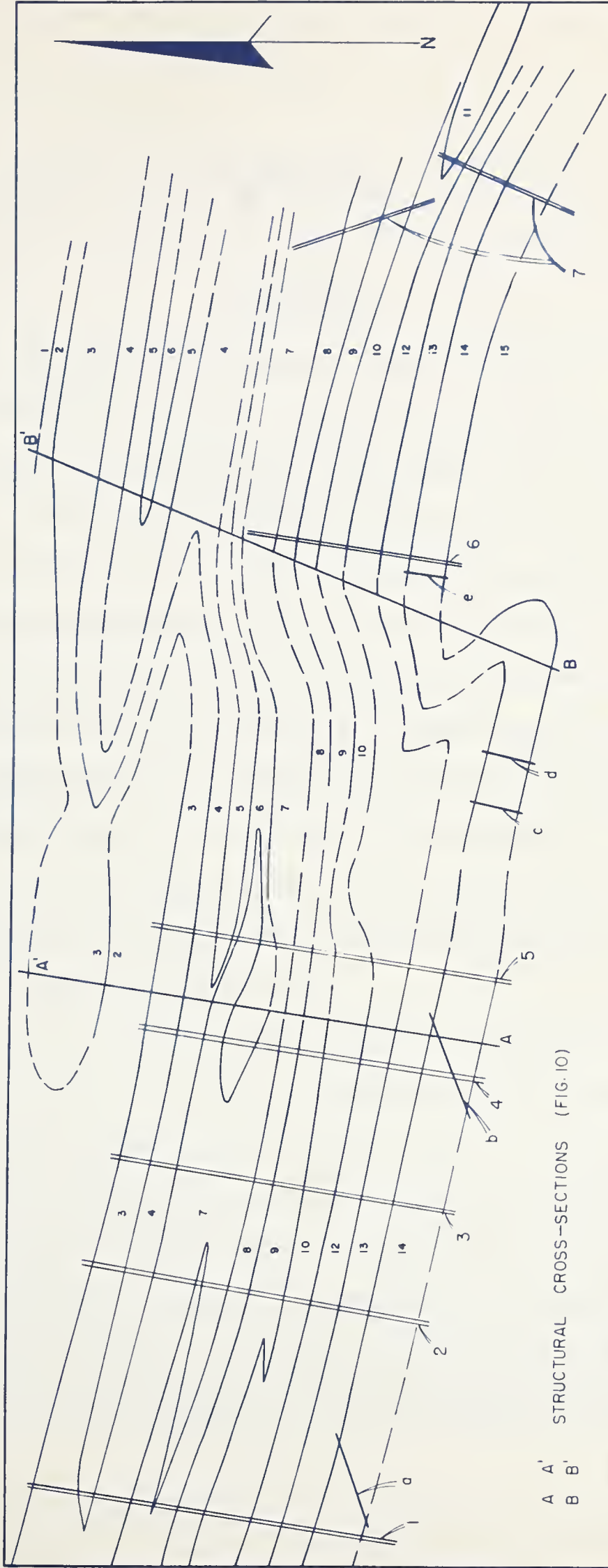


Fig. 2. Geologic Map of the Ski-Lodge Road Map-Area



A A' STRUCTURAL CROSS-SECTIONS (FIG. 10)
 B B'
 STRATIGRAPHIC CROSS-SECTIONS (FIG. 4)
 DETAILED SECTIONS IN UNIT 14 (FIG. 6)
 1. 2...3... UNIT NUMBERS

LOCALITY MAP
 FIG. 3

STRATIGRAPHY

Introduction

The rocks of the Ski-Lodge Road map-area are divisible into a number of interbedded, lenticular, arenaceous and argillaceous units, the maximum total thickness of which is about 1500 feet (figs. 2 and 4; Plate 1 A). Individual units are up to 300 feet thick and several pinch out completely within the area. Contacts are gradational over 2 to 5 feet where argillaceous units overlie the arenaceous, and are sometimes gradational over 1 foot to 2 feet but usually abrupt where arenaceous units overlie the argillaceous. Inter-fingering is common along many contacts (fig. 5). Sedimentary structures indicative of current deposition are common, especially in the arenaceous rocks. Although the ridge-forming arenaceous units are usually well exposed, extensive outcrops of the argillaceous units are few and are found mainly along the road and railroad cuts.

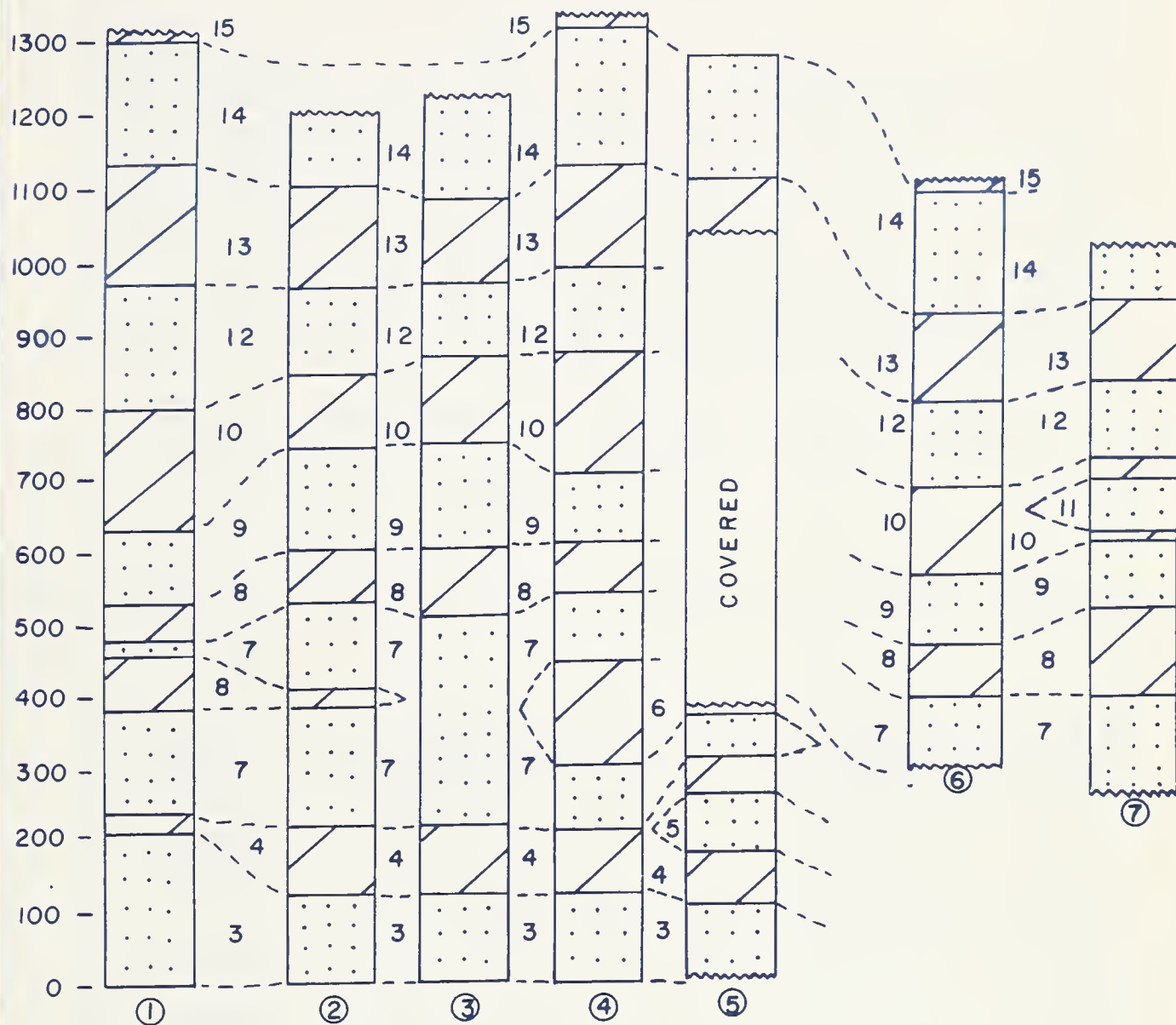
These rocks are within the Miette formation of Walcott (ibid, p. 340) who described it as consisting of "massive gray sandstone with interbedded gray and greenish gray siliceous shale". Charlesworth and Remington (1960, p. 12) restricted the term Miette to include only the interbedded sandstones, conglomerates, and argillites of Precambrian age. They referred the sandstones, conglomerates, and dolomites immediately above these beds, and below the Lower Cambrian Cavell formation, to the Jasper formation, and used the name Old Fort Point

formation to include the argillites, siltstones, intraformational breccias, and limestones below the Miette formation. The strata of the Ski-Lodge Road map-area occur in the lower part of the Miette formation as restricted by Charlesworth and Remington (ibid, p. 12). No fossils have been found in the Miette formation.

Arenaceous units

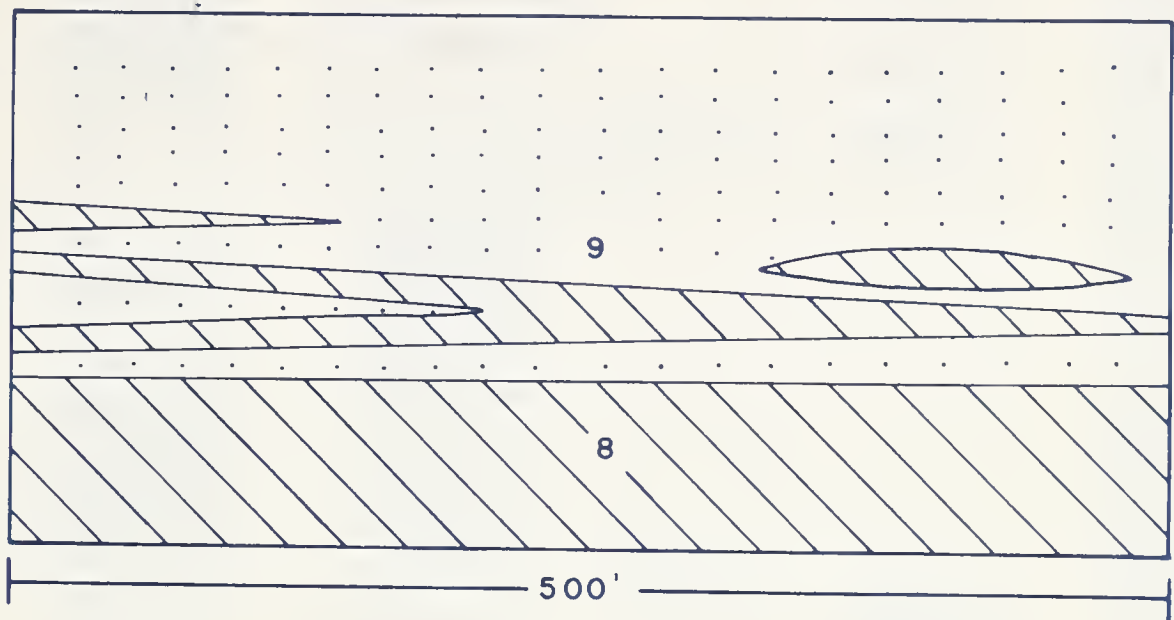
General. The arenaceous units consist of sandstones, pebble conglomerates and some interbeds of silty argillite and argillite (fig. 6). Individual beds within the units are usually from 6 inches to 10 feet thick, with a few beds as thin as 1 inch or as thick as 20 feet, and are rarely traceable more than 50 feet along strike. Lithologies change laterally by either gradational facies change or abrupt lensing.

Sedimentary Structures. Graded bedding of the waning current type described by Pettijohn (1957, p. 170) is very common and occurs in two ways. The first or continuous type involves a gradual decrease in grain size from the bottom to the top of a bed (Plate 1 B) and is often difficult to discern as the reduction may be small. The base of these beds is usually pebble conglomerate or coarse pebbly sandstone, while the top ranges from pebbly sandstone to argillite. It is not uncommon for a pebble conglomerate to grade to fine sandstone in one place, while ten feet away, within the same thickness, it grades only to coarse sandstone. These graded beds are usually between 3 and 6 feet thick



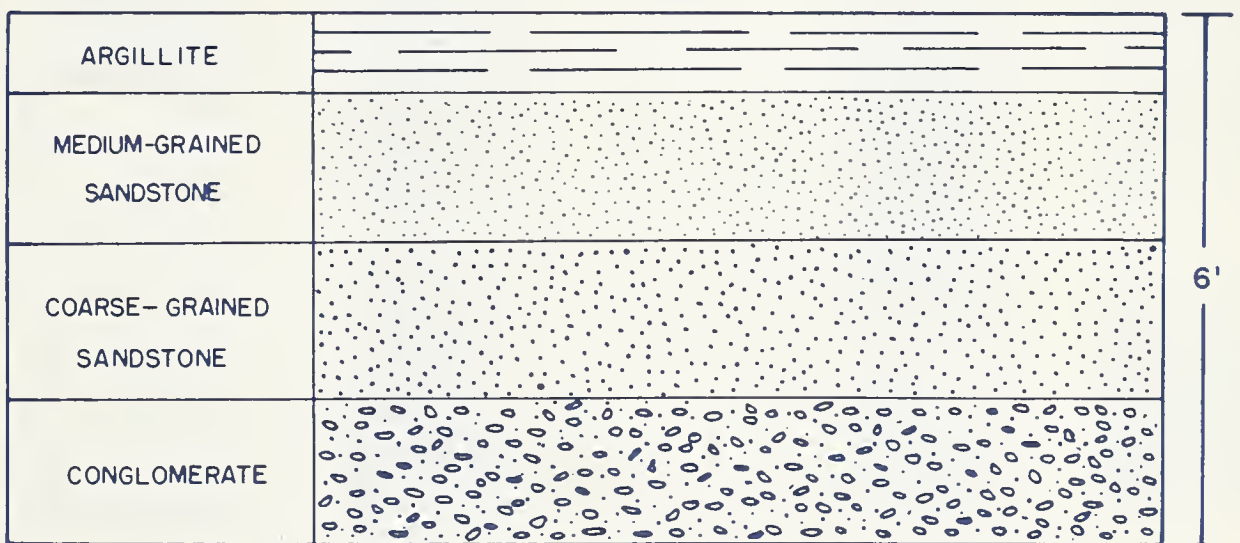
STRATIGRAPHIC SECTIONS INCLUDING UNITS 3-15
SEE FIG.3 FOR LOCALITIES

FIG. 4.



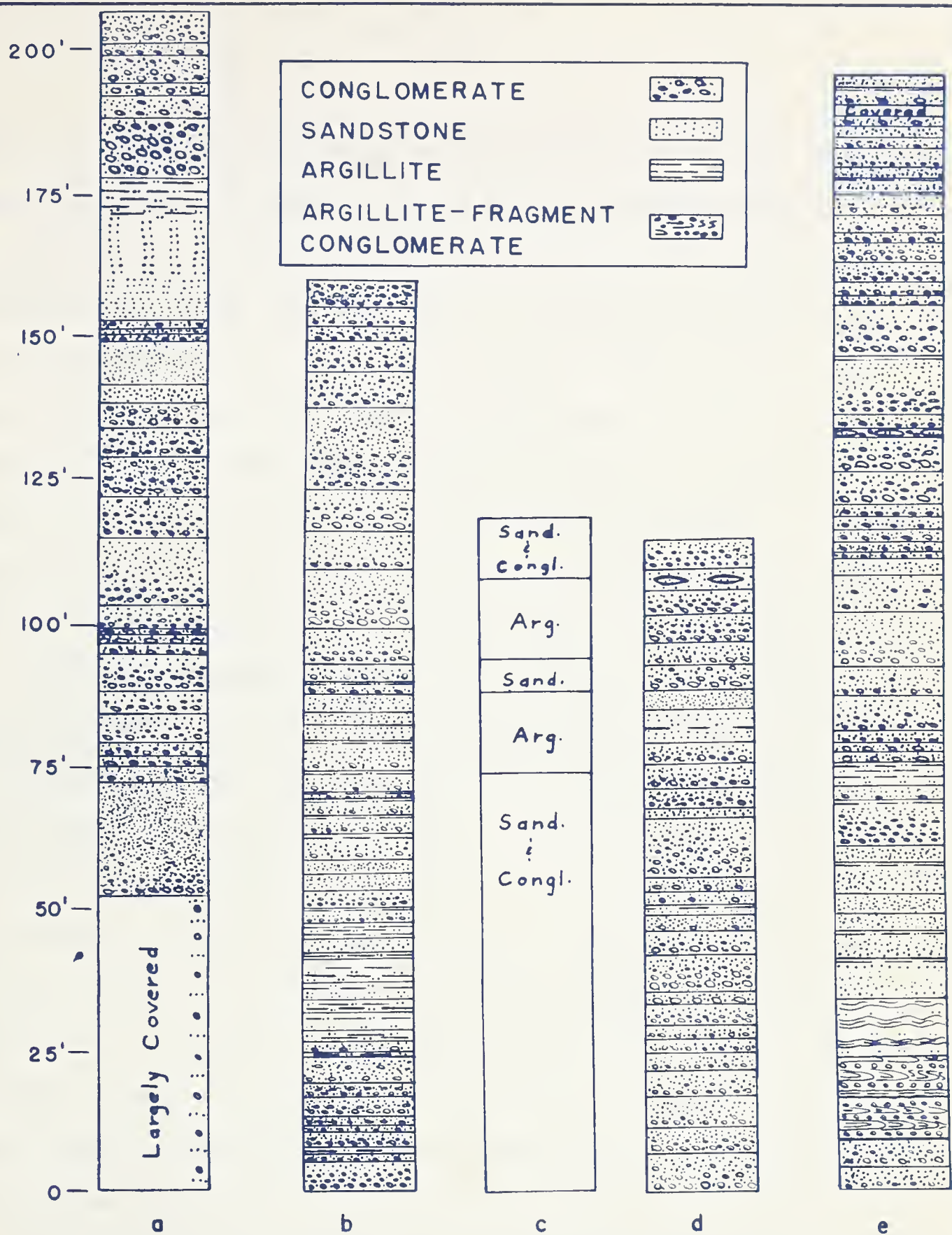
CONTACT BETWEEN UNITS 8 AND 9, EAST OF MIETTE RIVER

FIG. 5



A TYPICAL EXAMPLE OF DISCONTINUOUS GRADED BEDDING IN UNIT 14, ALONG RAILROAD

FIG. 7.



DETAILED STRATIGRAPHIC SECTIONS

IN UNIT 14
SEE FIG. 3 FOR LOCALITIES

FIG. 6

with a few as thin as 6 inches or as thick as 10 feet. The second or discontinuous type of graded bedding involves a number of sudden reductions in grain size from bottom to top such that the graded sequence consists of up to four beds, each with its own fairly constant grain size range (fig. 7). The bottom bed is usually pebble conglomerate or coarse pebbly sandstone while the top bed may range from coarse sandstone to argillite. Beds within the graded sequences are usually between 1 inch and 6 feet thick while the sequences range from 2 to 12 feet and average about 6 feet thick. Most beds within the arenaceous units are graded either continuously or, more commonly, discontinuously.

Cross-stratification is common and, following the terminology of McKee and Weir (1953), of the simple, trough, and planar types (Plate 1 C; Plate 1 E and F). The cross-strata are thinly bedded, consist of coarse pebbly to coarse sandstone and not uncommonly lie at the base of a continuously graded bed. Individual sets are between 6 inches and 3 feet thick, and between 3 and 20 feet long. Dips were measured on 30 randomly chosen sets, the poles to dip planes plotted on a stereonet, and the beds in which they occur rotated into the horizontal so that the cross-strata were in their original position of deposition. Dips range between 10 and 40 degrees and the general stream flow was toward the southwest (fig. 8).

Both symmetrical and asymmetrical scour-and-fill structures are common and are from 1/2 inch to 1 foot deep and 6 inches to 10 feet across (Plate 2 A). The scours are generally filled with pebble conglomerate or coarse sandstone, with the coarsest material in the center of the Scour. No general direction of stream flow could be ascertained from these structures.

PLATE 1

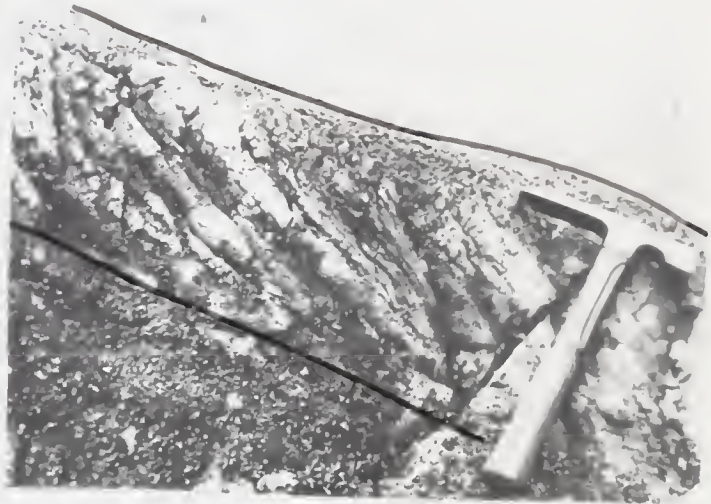
- A. A view looking southeast over the southeastern part of the map-area, showing interbedded argillaceous and arenaceous units 7-14.
- B. A poorly sorted graded bed within arenaceous unit number 14, 200 yards east of the Miette River. The rock is pebbly coarse sandstone grading up into coarse-grained sandstone and shows some preferred orientation of quartz pebbles.
- C. An example of simple cross-stratification in a coarse-grained sandstone of arenaceous unit number 12, 100 yards east of the Miette River.
- D. An example of trough cross-stratification in a medium-grained sandstone of arenaceous unit number 12, 150 yards east of Miette River.
- E. An example of planar cross-stratification in a coarse-grained sandstone of arenaceous unit number 9, 100 feet east of Miette River.



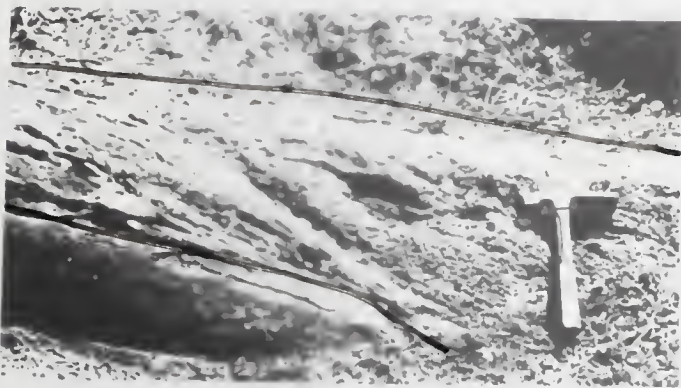
A



B



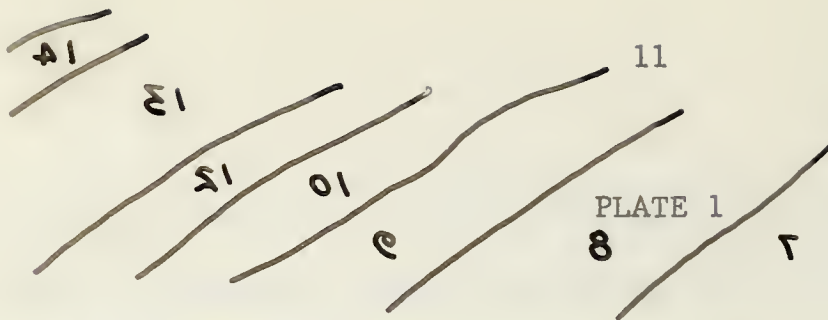
C



D



E



- A. A view looking southeast over the southeastern part of the map-area, showing interbedded argillaceous and arenaceous units 7-14.
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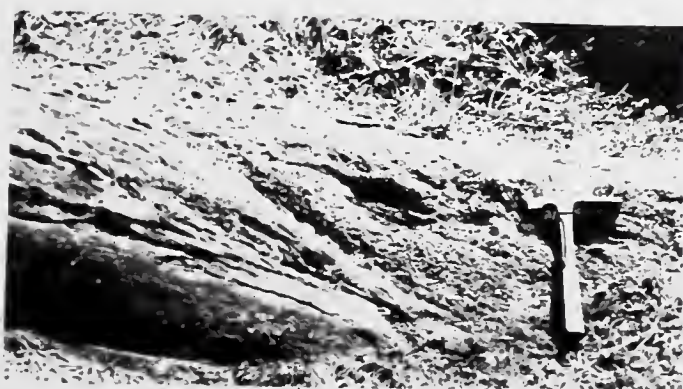
A



B



C



D

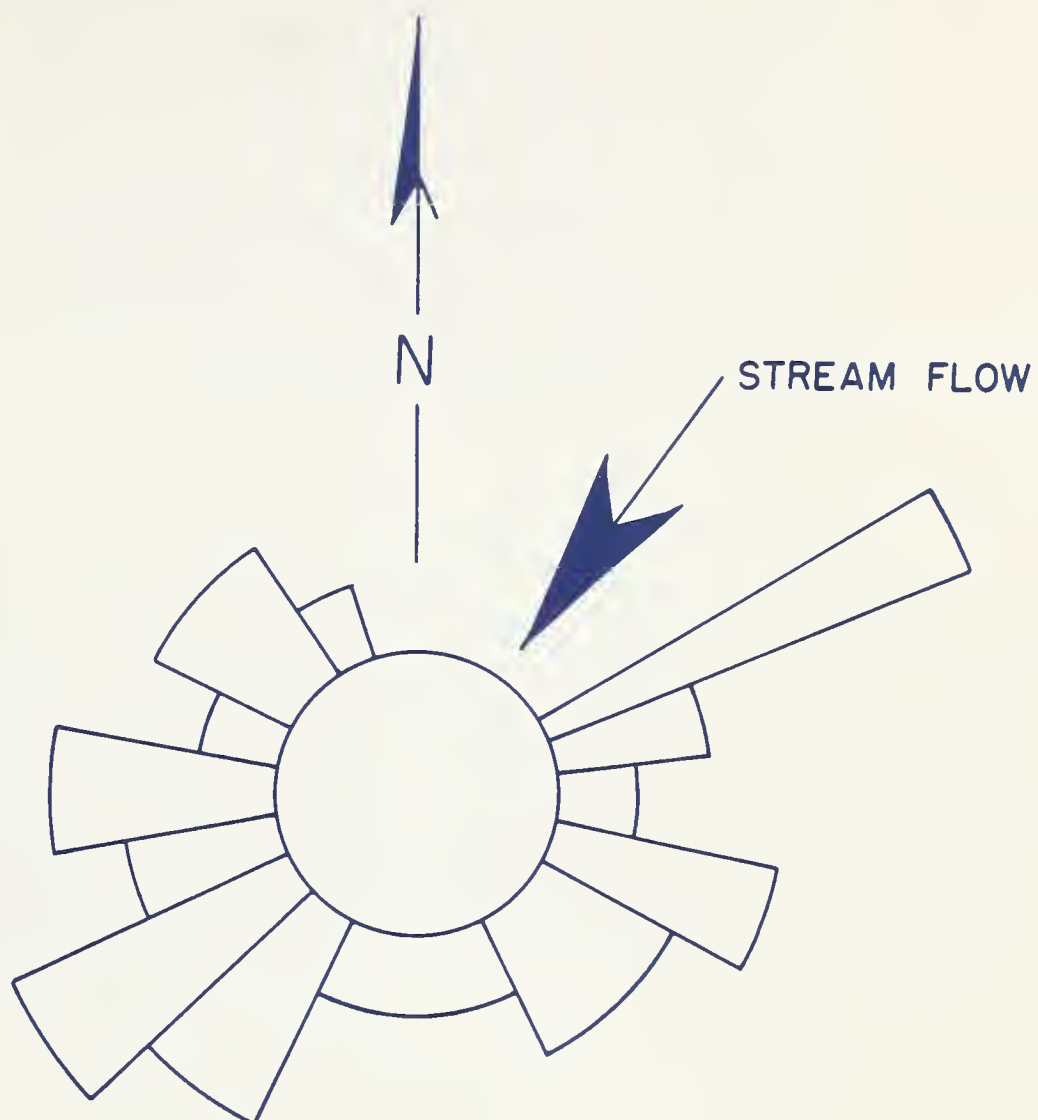


E

Infrequently, vague patterns suggestive of ripple marks may be seen on the top of fine sandstones, but it was possible at only two places to identify them as such and both were of the interference type.

Load-casting commonly occurs at the top of fine sandstones which are overlain by several feet of pebble conglomerate (Plate 2 B). The peak or "flame" of the cast is sometimes ruptured, resulting in the formation of double peaks (Plate 2 C). The average cast width is about 1 foot with a range between 3 inches and 3 feet. Down-slope slumping has distorted some load-casts to form structures similar to what Prentice (1960, p. 223) calls flow-casts (Plate 2 D). Assuming that the peak of the flow-casts originally pointed in the up-slope direction, the dip of the depositional surface was to the southwest. Only one example of penecontemporaneous folding was found and that was in the top arenaceous unit (Plate 2 E).

Description and Composition. On a fresh surface both sandstones and conglomerates are usually light greenish gray to greenish gray but may be light brownish gray. The weathered surface is generally darker but may be light reddish brown and is often flecked with limonite stains. Clusters of irregularly spaced, reddish brown iron-stained blotches, between 1 inch and 10 inches in diameter, are common. The rocks are very well indurated and, except where strongly weathered, hard to break. Grain-size sorting is poor to moderate, but a slight increase in sorting with decrease in grain size is discernible. The size range is from clay to pebbles 30 millimeters in diameter with the average

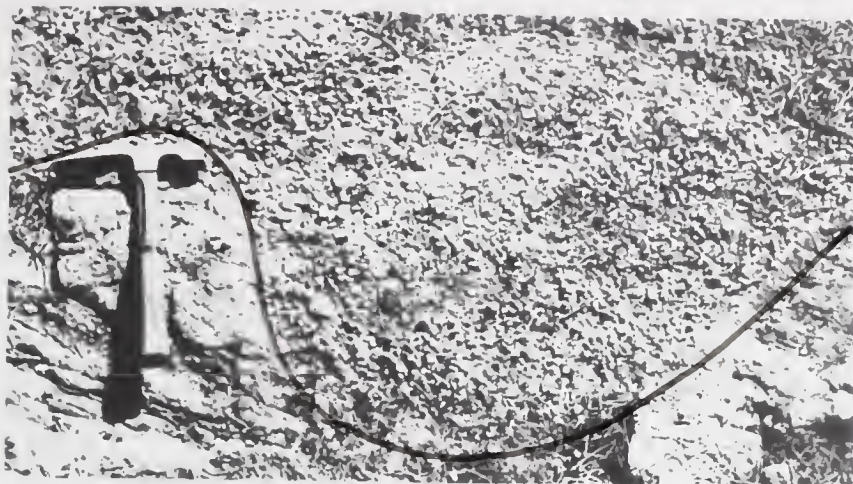


*ROSE DIAGRAM OF CROSS-STRATIFICATION
(40 READINGS)*

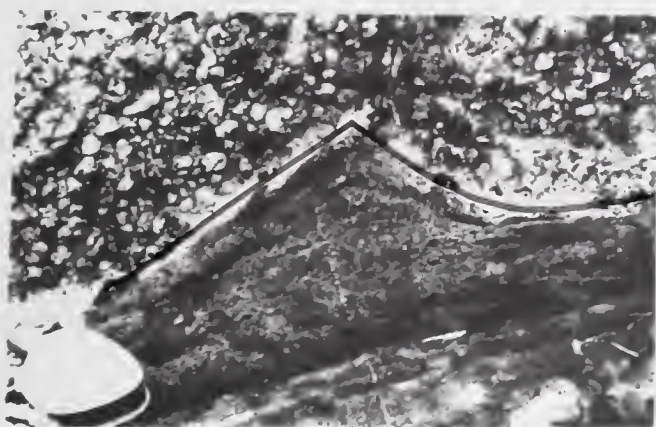
FIG. 8.

PLATE 2

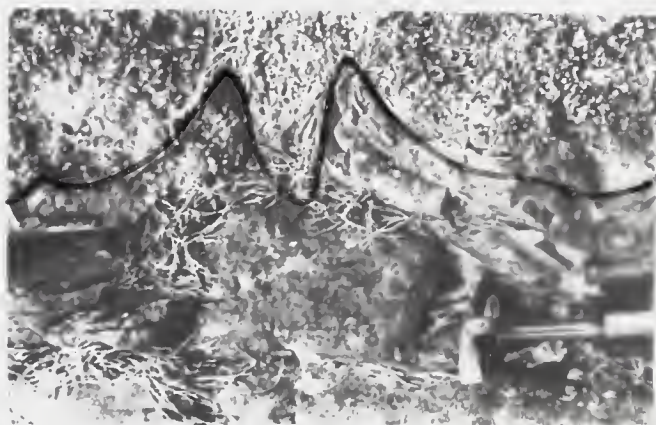
- A. A scour-and-fill structure in arenaceous unit number 9, 100 yards east of the Miette River. Rock below scour is medium-grained sandstone while that above is very poorly sorted pebble conglomerate.
- B. An example of load-casting at the base of a pebble conglomerate in arenaceous unit number 9, 100 yards east of the Miette River. Lower rock is fine-grained sandstone.
- C. A double peaked load-cast at same location and in same lithologies as in "B".
- D. Flow-casts on the base of a coarse-grained sandstone in arenaceous unit number 2, 1000 yards west of the railroad tracks.
- E. A penecontemporaneous fold or "slump" structure in fine-grained sandstone in arenaceous unit number 14, 1000 yards east of the Miette River.



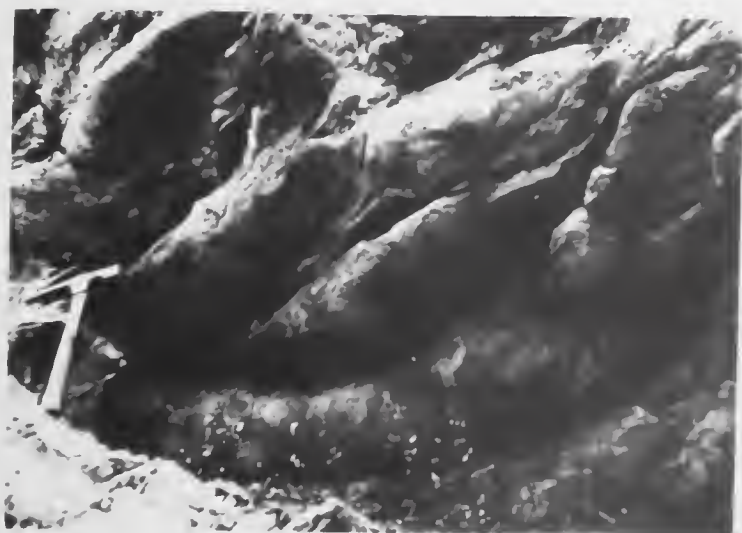
A



B



C

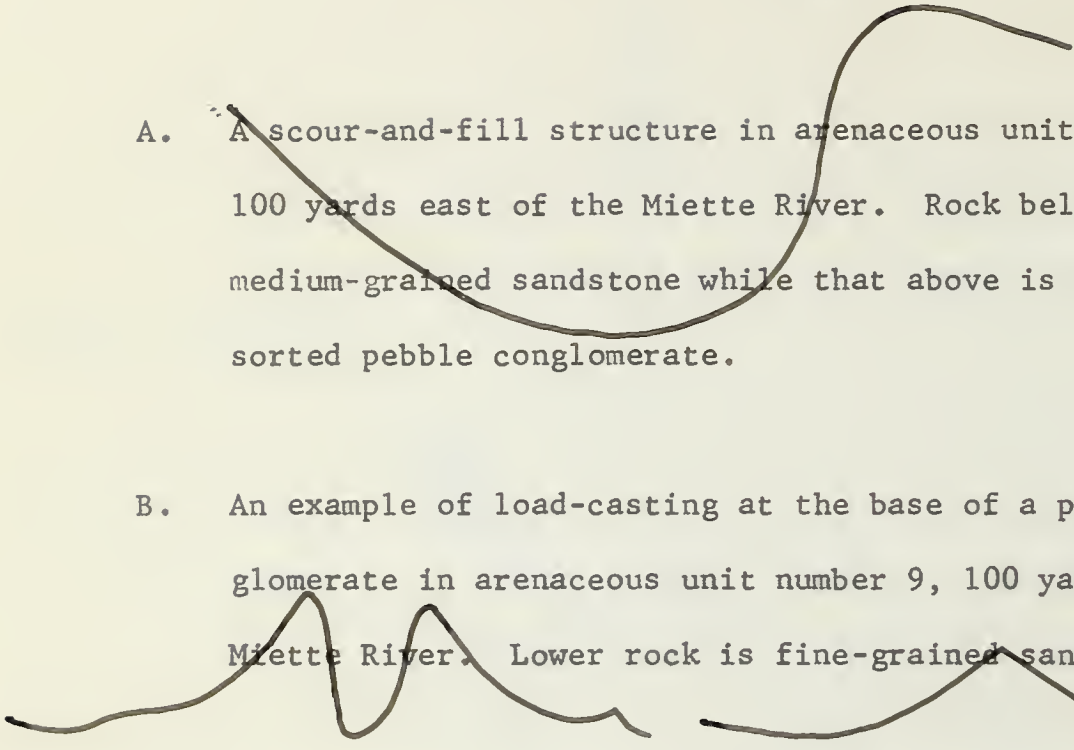


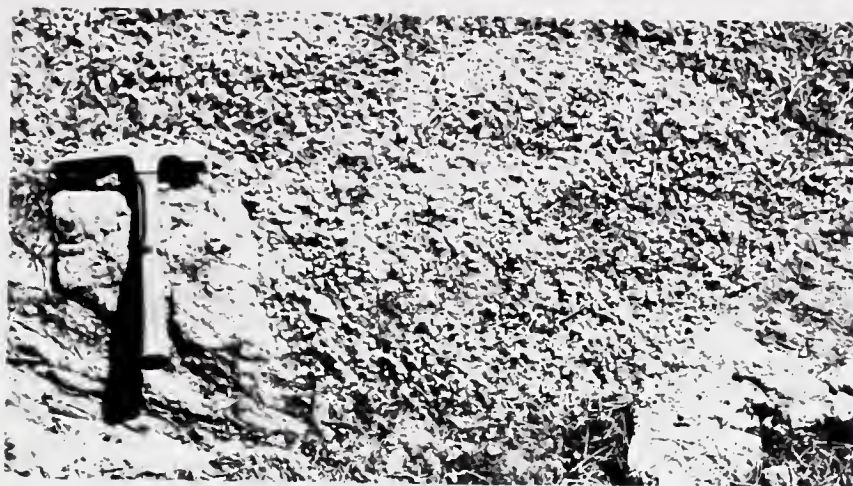
D



E

PLATE 2

- 
- A. A scour-and-fill structure in arenaceous unit number 9, 100 yards east of the Miette River. Rock below scour is medium-grained sandstone while that above is very poorly sorted pebble conglomerate.
- B. An example of load-casting at the base of a pebble conglomerate in arenaceous unit number 9, 100 yards east of the Miette River. Lower rock is fine-grained sandstone.
- C. A double peaked load-cast at same location and in same lithologies as in "B".
- D. Flow-casts on the base of a coarse-grained sandstone in arenaceous unit number 2, 1000 yards west of the railroad tracks.
- E. A penecontemporaneous fold or "slump" structure in fine-grained sandstone in arenaceous unit number 14, 1000 yards east of the Miette River.



A



B



C



D



E

being coarse sand. Pebbles are usually between 2 and 6 millimeters in diameter and the range in angularity is from subrounded for some pebbles to angular for most sand-sized grains (Plate 3 A to C).

The mineralogical composition is fairly consistent in both sandstones and conglomerates, with quartz ranging from 50 to 75 per cent and averaging 65 per cent, mica including chlorite ranging from 15 to 25 per cent and averaging about 20 per cent, carbonate ranging from 5 to 25 per cent and averaging about 10 per cent, feldspar ranging from 5 to 25 per cent and averaging about 10 per cent, accessory minerals considerably less than 1 per cent. Ignoring the carbonate, the rocks' average composition is that of a feldspathic graywacke, using the 1957 classification of Pettijohn (*ibid.*, p. 291).

There are three types of quartz. The most abundant occurs as single and composite grains of plutonic and hydrothermal origin, containing globular and dusty inclusions. Detrital composite grains of stretched metamorphic quartz are also common and are composed of fine sand- to silt-sized grains, often sub-parallel, and having strongly sutured contacts. Recrystallized quartz is not uncommon and occurs as indistinct composite grains composed of clear silt-sized crystals having weakly sutured contacts. Small quartz-chlorite-carbonate veinlets have sometimes produced a "percussion" type of straining in the larger quartz grains.

The feldspar was identified as plagioclase petrographically, by X-ray diffraction, and by the inability of sodium cobaltinitrate to stain it yellow (Hayes and Klugman, 1959, pp. 227-32). Petrographic evidence,

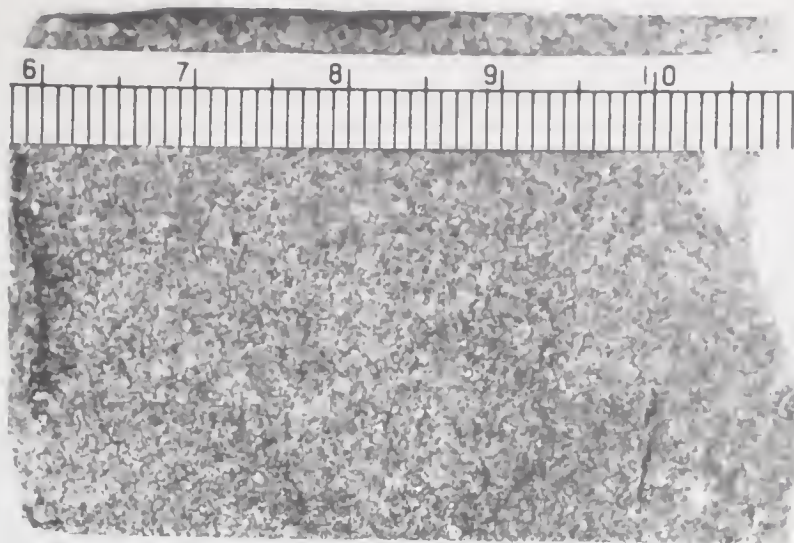
using the Michel-Levy method (Rogers and Kerr, 1942, p. 241), indicates it has a composition of An_{0-15} with an average of about An_9 , while its refractive indices (see Smith, 1958, p. 1189) indicates an average composition of An_5 . There are two types of feldspar having the same An composition: that in pebble-sized grains is commonly twinned following both the albite and pericline laws and sometimes the Carlsbad law (Plate 3 D), while most of that in sand-sized grains is twinned only on the albite law. The first type is similar to the chess-board twinned albite discussed by Starkey (1959, pp. 141-5), who suggested that it may result from the albitization of microcline or perthite, or from deformation of albitized potash feldspar. Possibly, however, it may also form from the deformation of already existing albite, or albitized calcic-plagioclase. The presence of authigenic crystal faces suggests that albitization did indeed play an important part in the formation of this feldspar. Remington (1960, p. 12) suggested that stress may have been important in their formation as only the larger grains are twinned in this manner. He believes that the larger grains would have been subjected to greater stress than the interstitial material and thus would be affected to a greater degree by deformation. This would be true, however, only if these grains were in contact with others of near equivalent size, which is not always the case, as many chess-board twinned grains are surrounded almost completely by much smaller material. It seems, to this writer, that the chess-board twinning was probably present in the detrital feldspar and that albitization has been the only post-deformational alteration to occur. Although pebble-sized grains are usually moderately rounded, the majority

of sand-sized grains have angular outlines and appear to have undergone greater recrystallization (Plate 3 E). Extinction in the normally-twinned albite is often irregular and fracturing is common. Although the feldspar is albitized some information regarding its original composition can be obtained. Abundant chlorite and muscovite replacement of most feldspar grains indicates that this feldspar was originally potassic, while carbonate replacement of some grains suggests, however, that calcic-plagioclase may also have been present. It seems probable that the original detrital feldspar was a mixture of potash and plagioclase feldspars.

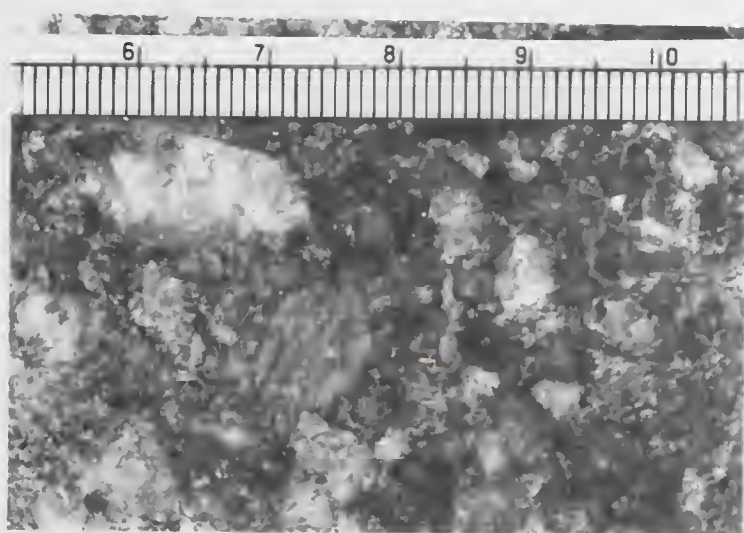
Detrital mica generally composes from 1 to 5 percent of the rock but in some thinly-bedded, micaceous, fine-grained sandstones it may be as high as 10 per cent and is usually oriented with the cleavage parallel to bedding. This mica occurs in sandwiches of biotite, chlorite, and muscovite, with the biotite forming a thin intermittent zone around the outside, chlorite forming a thicker zone inside the biotite, and muscovite in the center (Plate 4 A). These grains were probably originally biotite and partially altered to chlorite and muscovite during diagenesis or metamorphism. Muscovite, and sometimes carbonate, occur as alteration products of feldspar and, though usually occurring sporadically throughout the grains (Plate 4 B), are often concentrated along fractures and cleavage in the feldspar. Not infrequently, chlorite, and to a lesser extent muscovite, have partially replaced quartz grains. Chlorite is responsible for the greenish color of the rock and the dark green color of many feldspar grains.

PLATE 3

- A. Poorly sorted, medium-grained sandstone from arenaceous unit number 12, 10 feet west of railroad.
- B. Poorly sorted, angular grained pebble conglomerate from same location as sample in "A".
- C. Poorly sorted pebble conglomerate. The darker grain near the center is a feldspar grain partially replaced by chlorite and sericite. Taken from same locality as samples in "A" and "B".
- D. A chess-board twinned feldspar showing albite, pericline, and Carlsbad twinning. Sample from arenaceous unit number 12, 10 feet west of railroad. (60 X, crossed-nicols).
- E. An authigenic twinned feldspar. Sample from same locality as "A". (30 X, crossed-nicols).



A



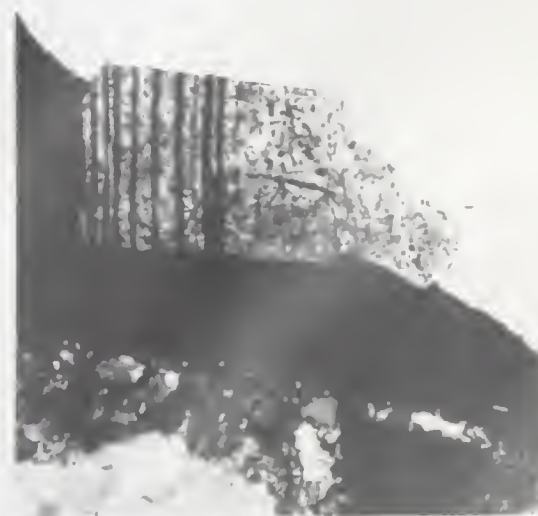
B



C



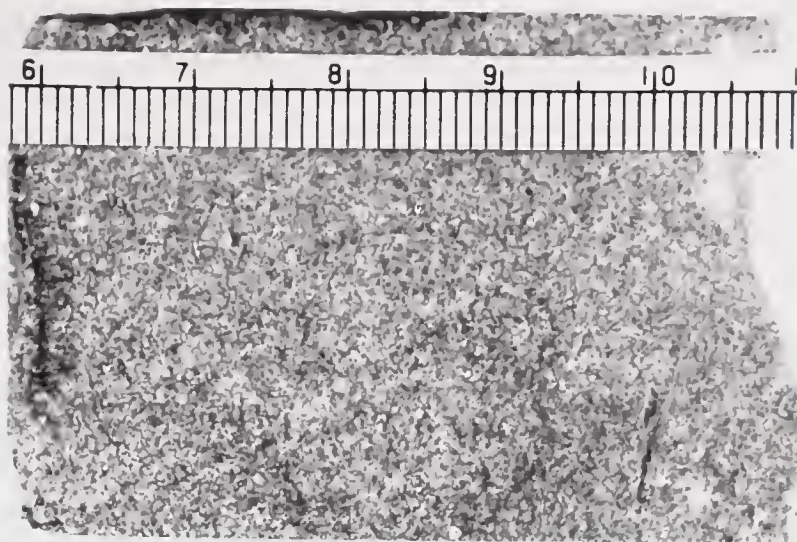
D



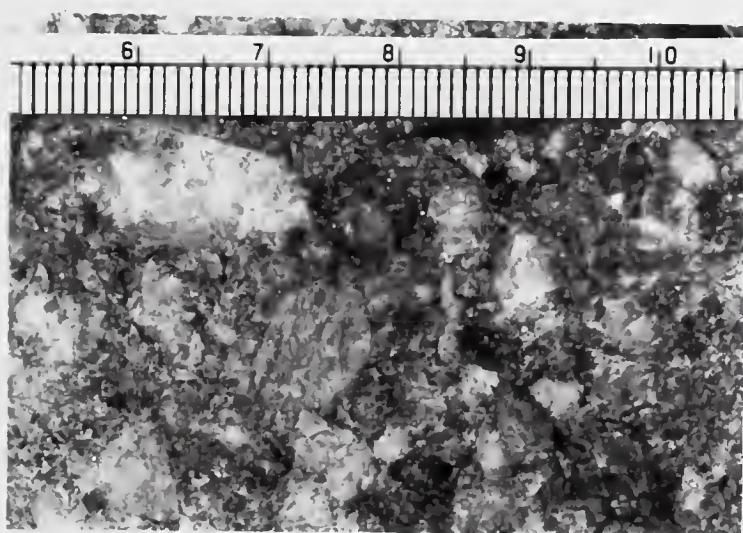
E

PLATE 3

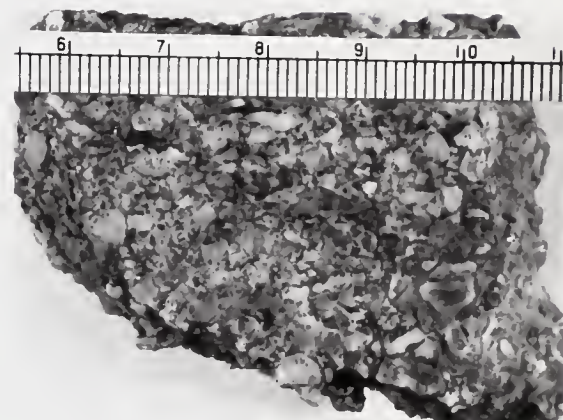
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- E. An authigenic twinned feldspar. Sample from same locality as "A". (30 X, crossed-nicols).



A



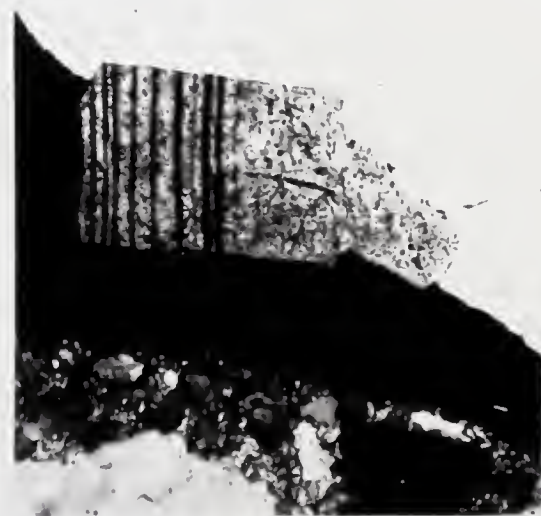
B



C



D



E

The carbonate is patchy and occurs as fine-grained cement, large twinned grains, and small untwinned grains replacing feldspar. Although some could have been detrital, the carbonate probably originated as exogenic cement and as an alteration product of feldspar. Calcite is the most common carbonate but siderite, and possibly some ankerite, are present in small rhombs often surrounded with a halo of limonite. Though highly variable, the average ratio of iron carbonate to calcite is about 1/5.

The amount of matrix is variable, averaging 15 per cent but composing nearly 30 per cent of some fine- to medium-grained sandstones, and consists of secondary muscovite and chlorite, and silt-sized quartz and feldspar.

Argillite rock-fragments are present in some conglomerates and coarse sandstone, and may be as large as 2 feet in diameter and 6 inches thick. In a few lenticular beds they make up more than 30 per cent of the rock which is then an argillite-fragment conglomerate. These argillite-fragment conglomerates have as a matrix mainly quartz pebbles with little smaller material, and the argillite phenoclasts, though often highly contorted, are usually parallel to bedding. The mineralogical composition of the argillite fragments is the same as that of the argillaceous units (see p. 29).

Heavy accessory minerals were studied from fine-grained sandstones in arenaceous units 9, 12, and 14 of stratigraphic section number 6 (see fig. 3 for location). Units 1, 3, 5, and 7 were analysed for heavy mineral composition by Remington (1960, pp. 14-18). Six samples, one from near the top and bottom of each unit, were taken and the "heavies" separated

using tetrabromoethane. So many "light" minerals came down with the "heavies" that a calculation of percentage by weight of "heavies" was not possible. The "heavies" were mounted for petrographic examination in Aroclor. Although both opaque and nonopaque heavy minerals were identified, a count was made only on the nonopaques. The main nonopaque heavy minerals identified, in order of abundance, were zircon, tourmaline, apatite, and rutile, but one possible grain of sphene and one grain of corundum were also present. Nonopaque heavy minerals are tabulated in figure 9 a, according to location in the stratigraphic sequence and relative abundance. There appears to be no trend to the distribution of heavy minerals in the section studied.

Zircon occurs as prisms averaging about 8 microns in length and usually having pyramidal terminations. Four varieties, based on color, were distinguished: 1) clear zircons, 2) pale hyacinths, 3) darker hyacinths, and 4) dark and near opaque malacons (see fig. 9 b for their relative abundance). All varieties of zircon show evidence of radioactive destruction; many grains have expansion-cracks radiating out from their centers, many have cloudy centers, and some colored ones are zoned, the intensity of coloration decreasing toward their peripheries. Zircons are more rounded than any other mineral. About 10 per cent are well rounded and rounded, 80 per cent are subrounded, and 10 per cent are subangular and angular, with no difference between the varieties. Many grains contain small globular and dusty inclusions and, less often, small, dark, rod-like, mineral inclusions.

Tourmaline appears in irregular flakes averaging about 12 microns in diameter. All grains are strongly pleochroic. Using the color produced by

the ordinary ray as a basis, three color varieties were distinguished:

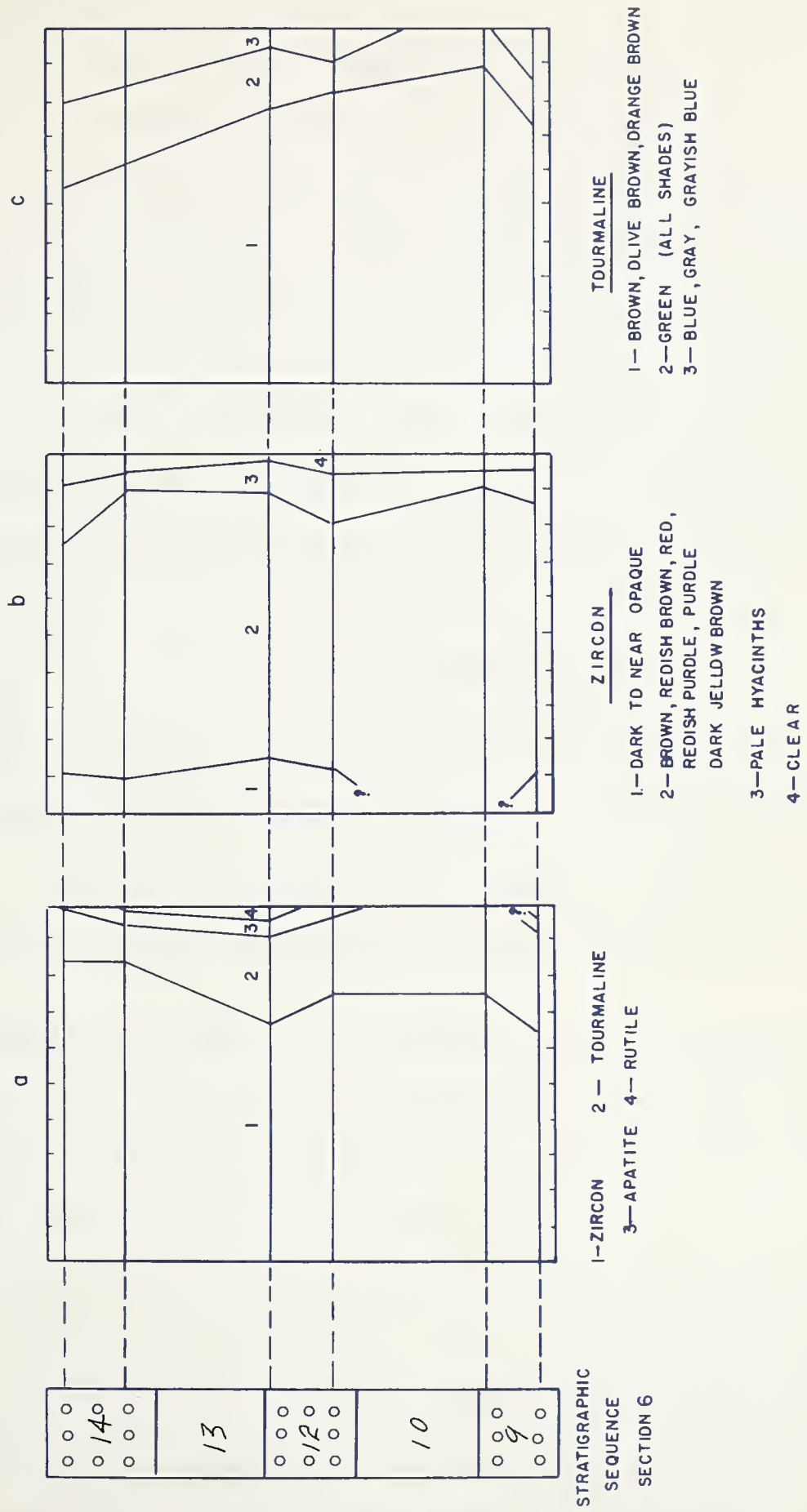
1) browns of all shades, 2) grass green, and 3) light to medium blue (see fig. 9 c for relative abundance and distribution). Most tourmaline grains are angular or subangular and nearly equi-dimensional, though some occur as prisms. Dusty and globular inclusions are common, except in the blue variety, and are generally aligned in rows.

Apatite is present in irregular flakes averaging about 10 microns in diameter and, though usually colorless, some grains are light brown. It is always angular to subangular and most grains contain globular and dusty inclusions.

Rutile occurs as prisms averaging about 6 microns in length and usually has subangular corners. It ranges in color from reddish brown to dark brown and many grains are coated with a white alteration product (leucoxene?). Some grains have oblique striations or fractures.

Ilmenite is the most common opaque heavy mineral and occurs as subangular grains generally coated with leucoxene. Some magnetite is present and commonly has secondary hematite associated with it. Although pyrite was present in the slides it is authigenic.

Authigenic pyrite cubes are common and occur in scattered clusters throughout the arenaceous units. They range in size from microscopic to 3 inches wide, with an average of about 1/4 inch. Usually those exposed to the surface are badly weathered and may be completely destroyed, leaving a subrounded, cube-shaped hole in the rock (Plate 4 C). The weathering of this pyrite is responsible for the blotches of iron stain so apparent in many outcrops. The pyrite probably grew during shallow burial as a result



TABULATION OF HEAVY MINERAL SPECIES AND VARITIES AND THE LOCATION IN THE

SECTION a.) MINERAL SPECIES, b.) ZIRCON VARITIES, c.) TOURMALINE

VARITIES.

FIG. 9.

of organic decay in a reducing environment and, as indicated by the presence of calcite cement in the rock, at a pH greater than 7.8 (Krumbein and Garrels, 1952). Most pyrite crystals are surrounded by a recrystallized rim of quartz in the rock and many have rounded quartz inclusions. Growth of the pyrite was initially by replacement of the more easily pressure-dissolved materials in the rock and by inclusion of those quartz grains which were not able to dissolve as fast as the pyrite grew. Some crystals grew faster than the surrounding material was able to dissolve, and thus deformed the rock by compacting and wrinkling it around the pyrite-rock interface (Plate 4 C).

Argillaceous Units

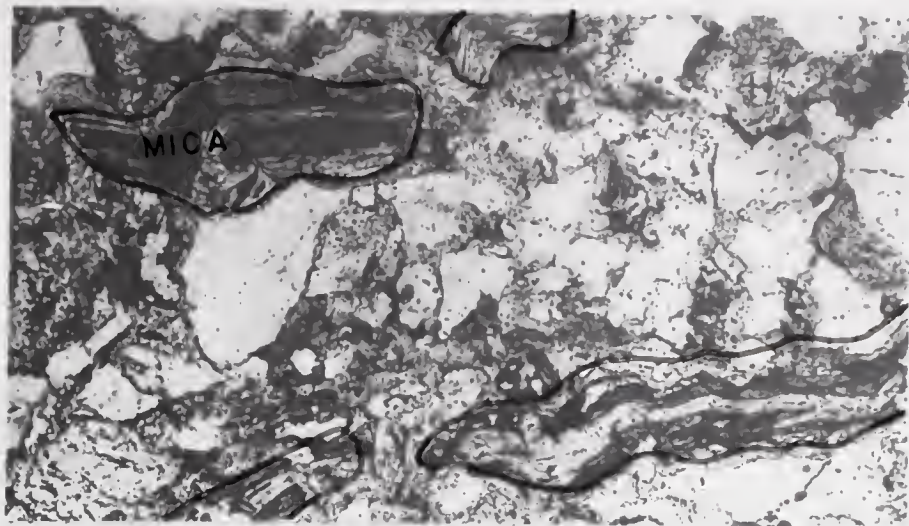
General. The argillaceous units consist of argillite, silty argillite, and siltstone with some interbeds of sandstone and conglomerate up to 3 feet thick. The argillite is very thinly bedded to laminated and beds are usually laterally persistent, though some sandstone and siltstone bands are lenticular.

Sedimentary Structures. Very irregular, simple and trough cross-stratification occurs in many fine sandstone and siltstone bands (Plate 4 D). These cross-stratified bands range from 1/2 inch to 3 inches thick and are seldom persistent for more than 100 feet along strike.

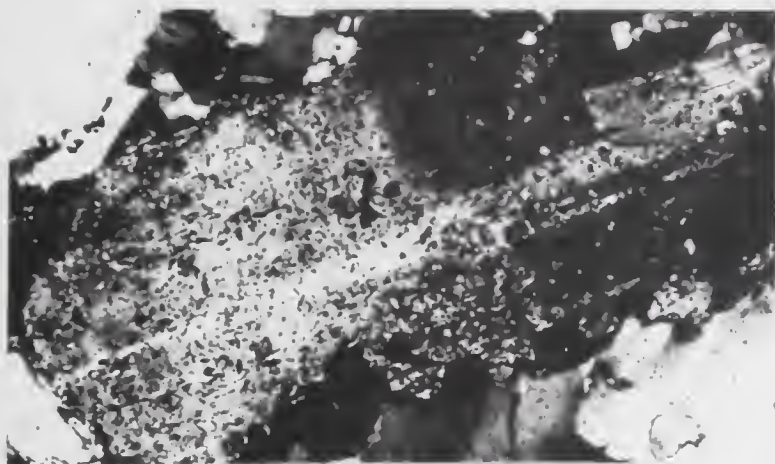
Graded bedding is very common and occurs in varve-like beds ranging from 1/10 to 1 inch thick (Plate 4 E). The olive-gray siltstone or silty argillite which usually comprises the base of a graded bed grades up into dark olive-gray, slightly silty argillite, or, in some cases, into dark gray argillite. Small scale load-casting is not uncommon on the base of many graded beds (see Plate 8 B).

PLATE 4

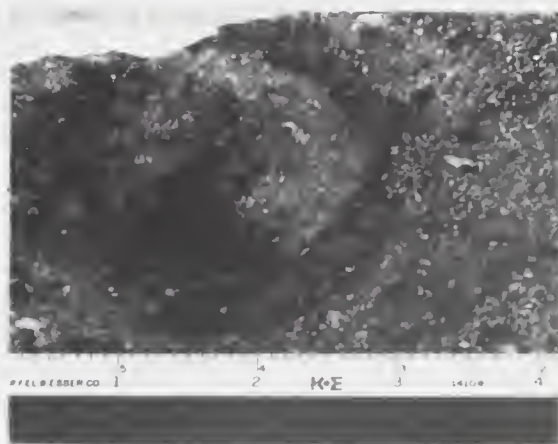
- A. Mica sandwiches in a fine-grained sandstone from arenaceous unit number 9, 100 feet east of the Miette River. (25 X).
- B. Albite twinned feldspar partially replaced by chlorite and sericite. Sample from arenaceous unit number 12, 10 feet west of railroad. (60 X, crossed-nicols).
- C. A hole left by the weathering of a pyrite cube in arenaceous unit number 3, 50 feet west of Whistlers Mountain Trail.
- D. A cross-laminated siltstone band from argillaceous unit number 10, 100 yards east of the Miette River.
- E. Varve-like graded bedding from argillaceous unit number 10, 20 feet west of railroad. The base of one graded bed shows load-casting.



A



B



C



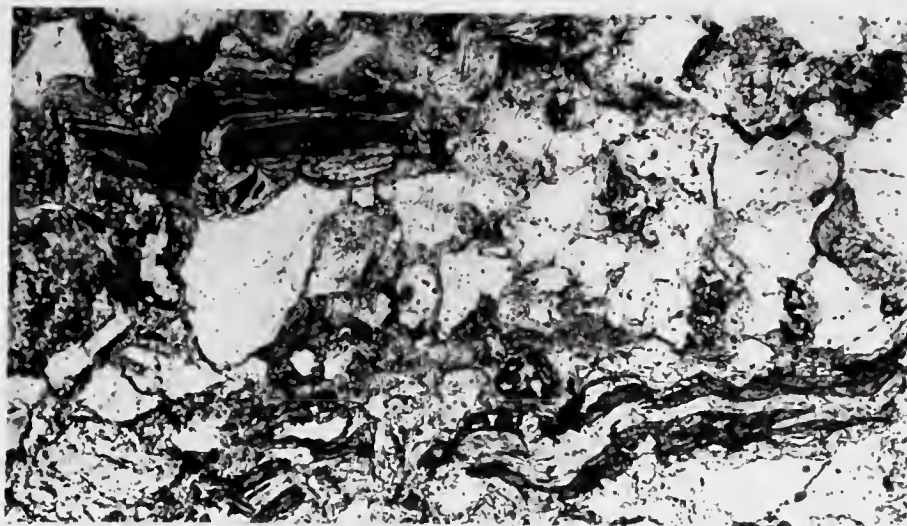
D



E



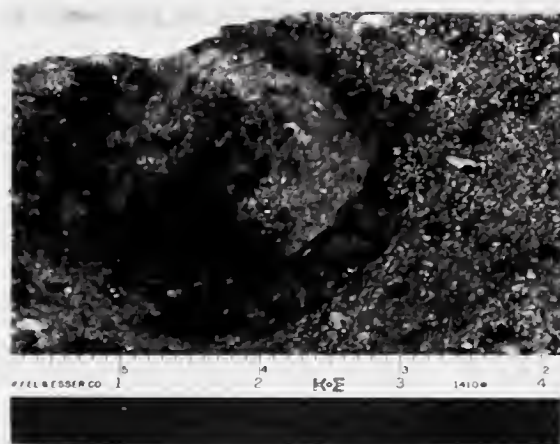
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A



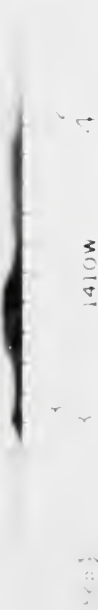
B



C



D



E



Description and Composition. The argillite is usually well indurated and hard to break, especially where slaty cleavage is poorly developed. Although the rock generally weathers rusty brown or maroon, some irregular patches have weathered grayish-olive. Fine-grained recrystallized muscovite and chlorite make up most of the rock with an extremely variable content of fine sand- and silt-sized quartz, the average being about 15 per cent. Less than 5 per cent coarse detrital muscovite is present and is aligned parallel to bedding. Ilmenite, zircon, and magnetite occur as heavy varietal minerals and, though usually scattered throughout the rock, are not uncommonly in bands several mineral grains thick. They are more abundant in the siltstones and silty argillites than in rocks of any other grain size. Carbonate cement is patchy and only rarely present, even in fresh samples taken from the road and railroad cuts. Though cleavage is common, only rarely is enough muscovite and chlorite aligned parallel to it to cause a sheen.

Age and Correlation

Correlation with the rocks in other areas can be effected only on the basis of stratigraphic position and lithological similarities. The Hector formation in the Bow Valley (Walcott, 1910, p. 428), the Horsethief Creek formation in Southeastern British Columbia (Walker, 1926, p. 14), and the Miette formation in the Jasper Valley, all contain beds of argillite, sandstone, and feldspathic sandstone, and all three are in the Upper Precambrian. From this evidence, Reesor (1957, p. 160) has correlated them. However,

Evans (1960, p. 25) has correlated the Old Fort Point formation (underlying the Miette formation) with the Hector formation. The Miette formation may then correlate only with the uppermost part of the Hector formation or its equivalent may not be present in the Bow Valley.

Provenance and Depositional Environment

Introduction. The mineralogy and texture of the rocks in the Miette formation, though partly the result of metamorphism, may be used to deduce the lithological and mineralogical composition of the source area and, with the aid of information obtained from sedimentary structures, may be used to infer the depositional environment.

Discussion of Provenance. Both feldspar and plutonic quartz are present and indicate the existence of igneous rocks in the source area. The feldspar is probably mainly from an acidic-igneous or metamorphic source but some may be from an intermediate- or basic-igneous source. Though the chess-board twinned feldspar could have been formed from either granitic or pegmatitic microcline, or perthite, the large size of most grains suggests mainly a pegmatitic source.

The nonopaque heavy minerals are of limited help in determining provenance as only the ultra-stable suite, zircon, tourmaline, apatite and rutile, is present. This would suggest either a reworked sedimentary source, long-time abrasion from source to site of deposition, or that intrastratal solution has removed the less stable minerals after deposition. The last possibility is preferred because the presence of apatite and feldspar in the rock and the strong angularity of the tourmaline and apatite suggest

a close primary source. The rounding of many zircons is probably due to deuteric action within the igneous rocks during their crystallization, rather than by abrasion during transportation.

Since the coloration of zircon is due to the bombardment by radioactive-decay particles on the crystal lattice, the different colors of zircons in the Miette rocks may be a function of either source age or content of radioactive material (the greater coloration occurring in the older zircons, or in those containing the most radioactive material). If it is assumed that the zircons are all of the same age then the variation in color is due to a difference in content of radioactive material. According to Adams (1960; H. Baadsgaard, 1961, personal communication), zircons from volcanic sources contain less radioactive material than do zircons from plutonic sources. The clear zircons in the Miette formation, possibly containing little radioactive material, may then be from an extrusive source while the majority of zircons are probably from a plutonic source.

The tourmaline probably indicates a granitic or pegmatitic source while the presence of apatite and rutile may suggest acidic-plutonic and basic-plutonic sources respectively (Pettijohn, *ibid.*, p. 513).

The opaque heavy minerals, ilmenite, and magnetite, are not good source indicators but are generally more common in intermediate- and basic- than in acidic-igneous rocks.

Composite grains of stretched metamorphic quartz, which could represent either a sheared sedimentary, sheared metamorphic, or sheared plutonic source (Folk, 1959, p. 70), are the only metamorphic rock fragments present, and there are no detrital metamorphic minerals.

Due to the angularity of the quartz the existence of sedimentary rocks in the source area is thought to be unlikely.

The angular and coarse nature of the grains in the rock suggest a short period of transportation from source to site of deposition, and the coarse grains suggest a topographically high source undergoing rapid physical breakdown. Cross-stratification and flow-cast studies indicate that this source was to the northeast of the site of deposition and thus may have been within the Canadian Shield.

Discussion of Depositional Environment. Cross-stratification, waning-current, graded bedding, lenticularity of beds, and rapid lateral grain-size changes, all typical features of top-set deltaic deposits (Rich, 1951, pp. 1-20), are present in the arenaceous units of the Miette formation. Except for a few occurrences of flow-casts, evidence of intra-stratal flow and slumping is rare and the site of deposition may have been generally quite flat. Cross-stratification and graded bedding in the argillites suggest stream influence and they were probably deposited in inter-distributary bays and lagoons and as delta fore-set beds.

The argillite-fragment conglomerates are intraformational and probably a result of flood redeposition of shale from dried up lagoonal areas or tidal flats. The individual quartz pebbles in these conglomerates rarely indent the fragments thus the shale must have been quite well compacted before redeposition.

Summary of Provenance and Depositional Environment. The mineralogy and texture of the rocks in the map-area suggest a close, topographically

high, mainly acidic-plutonic (including pegmatitic) source, containing some volcanic, possibly basic- or intermediate-igneous rocks, and some metamorphic rocks. It is unlikely, however, that the source area actually contained mostly igneous, and few metamorphic rocks. Most minerals indicative of a metamorphic source are more easily destroyed by transportation and intrastratal solution than those indicative of an igneous source. The mineralogical evidence may thus be misleading and metamorphic rocks may have been at least as abundant in the source terrane as were igneous rocks. The derived detritus was deposited rapidly in a subsiding deltaic region not far from the source area.

STRUCTURE

Introduction

During the Laramide orogeny the Precambrian rocks in the Jasper area were folded into a series of anticlinoria and synclinoria. The strata of the Ski-Lodge Road map-area are situated on the southwest limb of one of these folds, the Jasper anticlinorium, the axis of which trends west-northwest and lies some 1 1/2 miles to the north-northeast. The axis of the adjacent, similarly trending synclinorium probably runs through the unexposed ground about 1/4 miles south of the area. Within the map-area the general structural trend is north 80 degrees west but varies within a 40 degree range. Dips are usually steep and range from 35 degrees to 60 degrees overturned, averaging 65 degrees for south-dipping beds and 50 degrees for north-dipping beds. Four minor folds, grouped into two anticline-syncline sets, are present but no faults were observed. Joints are common, especially in the arenaceous units which have eleven different sets, six of which are very common and can be seen on most outcrops.

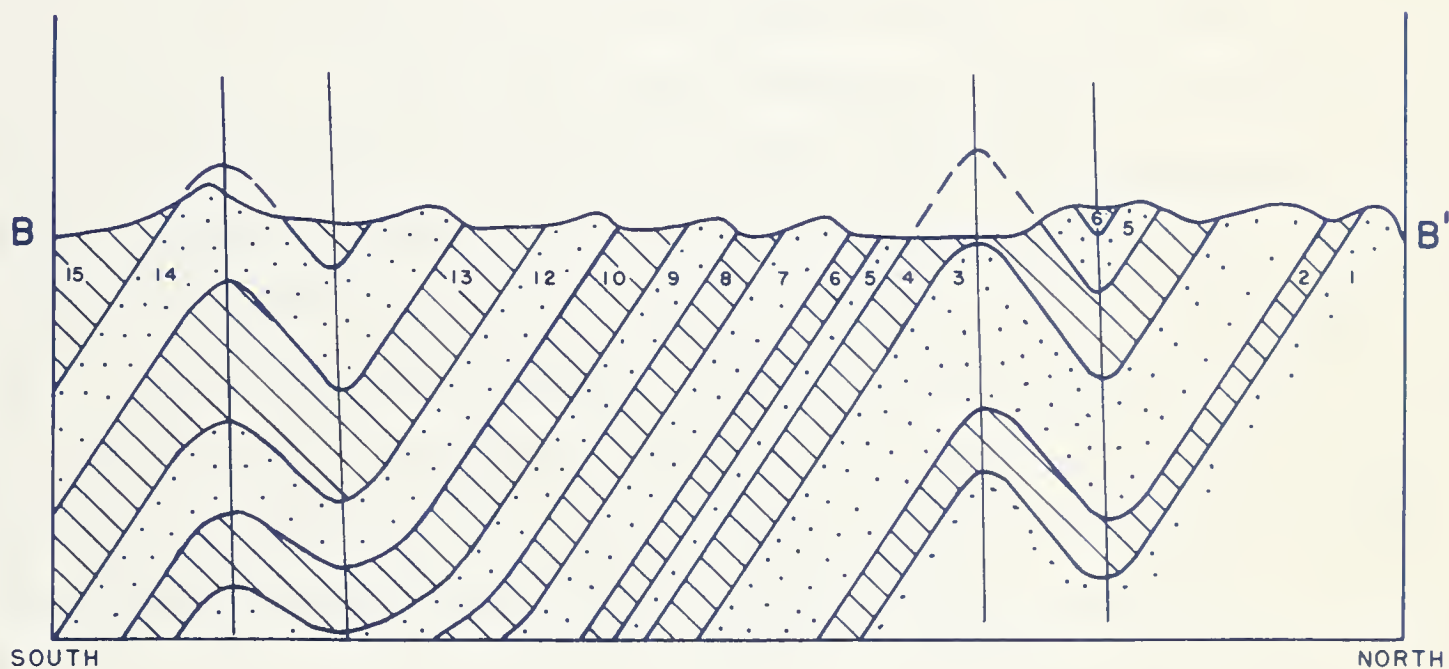
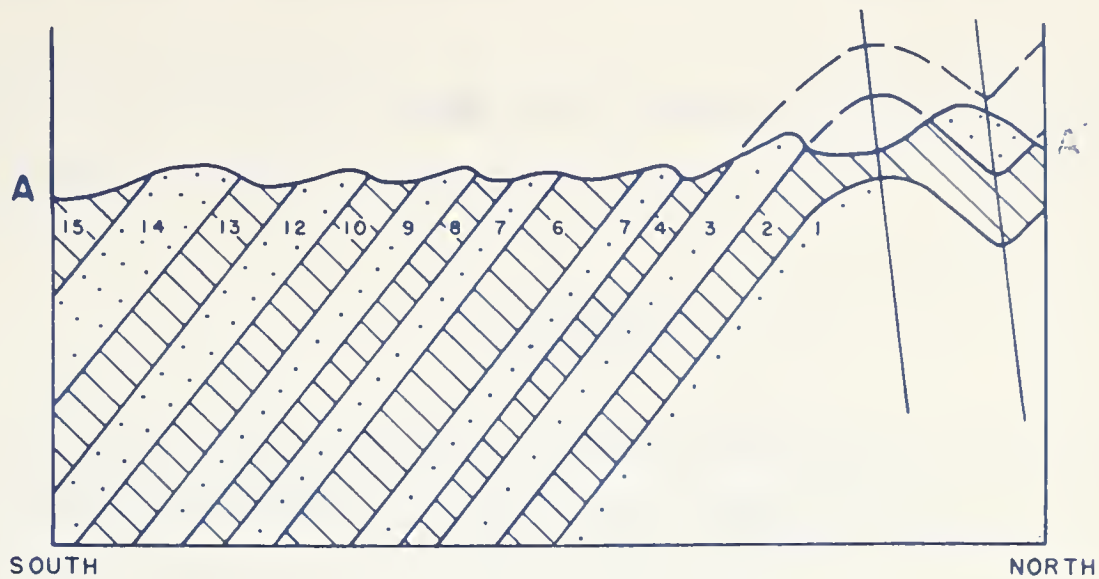
Minor Folds

In the larger of the two fold-sets, which runs along the northern part of the area (fig. 2), the axial planes are parallel and range in strike from north 75 degrees west in the west to north 80 degrees west in the east, and dip from 70 to 80 degrees north. The distance between axial traces is 300 feet while the structural relief averages about 500

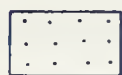
feet. Along the trough of the syncline the plunge, as measured directly, varies locally both in direction and in amount, the maximum plunge to the east being 15 degrees and to the west 25 degrees. Two hundred feet east of the road, along the anticlinal axis, the relation between bedding and cleavage suggests a 10 degree east plunge while 1000 feet west of the road the plunge, directly measured, is 5 degrees east. The asymmetrical nature of the folds is indicated by the southern dips averaging 65 degrees while the dip of the common limb is about 50 degrees north.

The smaller fold-set is situated about 1300 feet south of the larger but is slightly oblique to it. The axial planes, which both dip 70 degrees north, converge to the northwest and range in strike from north 80 degrees west at the convergence point to north 60 degrees west in the case of the anticline and north 65 degrees west in the case of the syncline, in the southeast. The distance between axial traces ranges from 0 to 350 feet and the structural relief from 0 to 500 feet. At the southeast end both syncline and anticline reach their maximum plunge, 15 and 30 degrees east respectively. The asymmetrical nature of the folds is indicated by the southern dips, on the north limb of the syncline and the south limb of the anticline, averaging 60 degrees and 65 degrees respectively while the dip of the common limb is about 50 degrees north.

The general dip of the strata towards the synclinorium can be approximated as the angle of slope between the troughs of the minor-synclines or the crest of the minor-anticlines. This is found from the cross-sections (fig. 10) to be about 45 degrees. Prevalent bedding-plane slippage in the arenaceous units indicates that they have tended



0 100 200 YARDS



ARENACEOUS UNITS



ARGILLACEOUS UNITS

STRUCTURAL CROSS-SECTIONS SEE FIG. 3 FOR LOCALITIES

FIG. 10

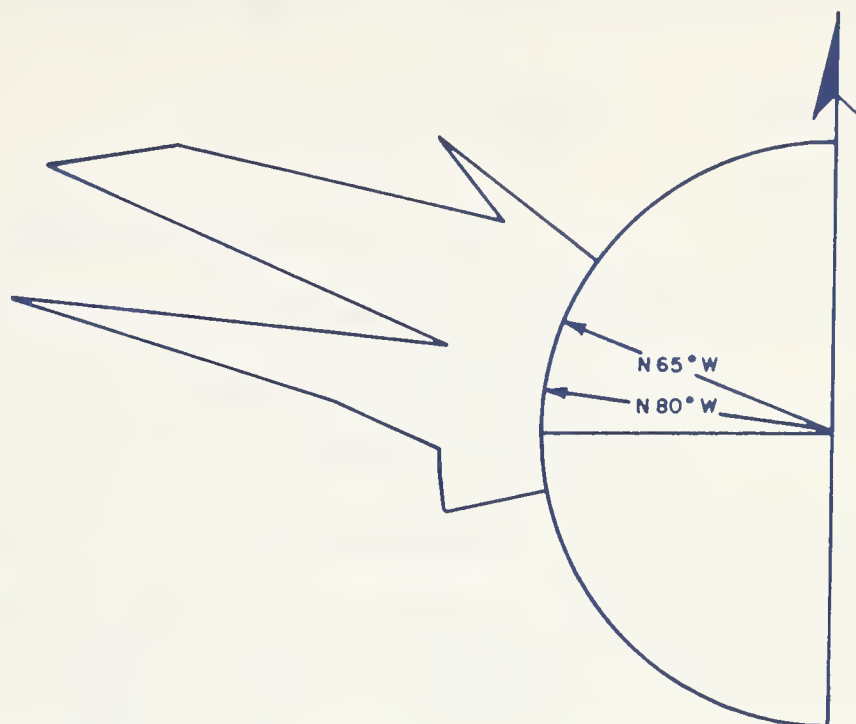
to fold in a "concentric" manner while cleavage in the argillaceous units suggests folding of a "similar" type.

Cleavage

The flow-cleavage present in the argillites has two major orientations with average strikes of about north 80 degrees west and north 65 degrees west (fig. 11). The strike of the first set is approximately parallel to the regional structural trend while the second is nearly parallel to the average direction of the axial traces of the smaller minor-fold set. It can be seen on the cleavage map (fig. 12) that the second set dips mainly to the north and that outcrops having this set cluster around the smaller minor-fold set, although there are some around the larger minor-fold set. The first set dips mainly to the south and is steeper than the second set. The two cleavage readings in the southeastern part of the map are a special case as both bedding and cleavage are swinging to have a more northerly strike. It is not known if there is any age difference between the cleavage sets.

Joints

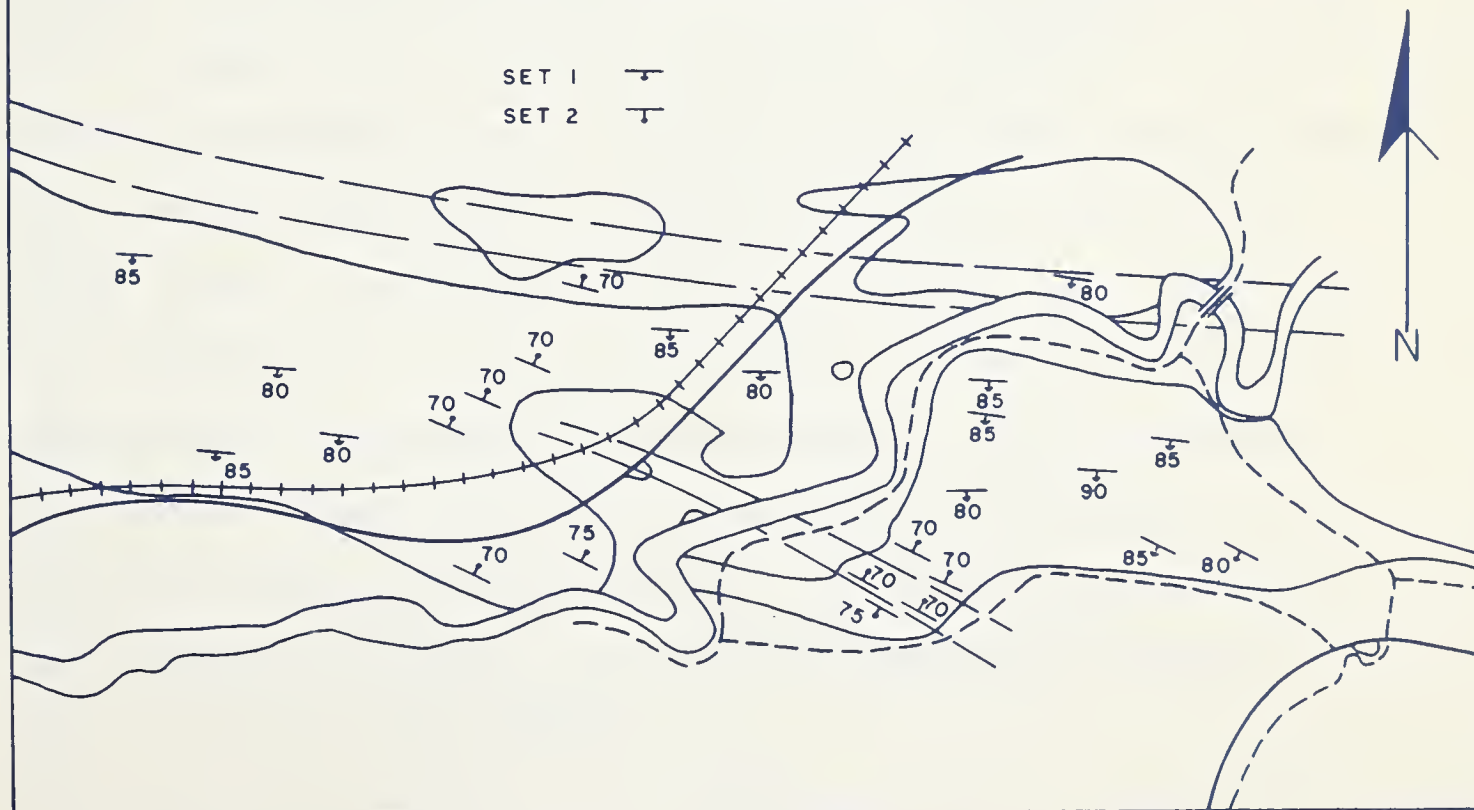
Introduction. The contour pattern of poles to joint-planes on a Schmidt equal-area net was used to find the orientations of joint-sets within the map-area. H.J. Pincus (1951, p. 81) suggested the use of the Poisson function for finding the probability of a cluster representing isotropism. Although Pincus used the function with rectangular co-ordinate paper it can



ROSE DIAGRAM OF CLEAVAGE STRIKES, BASED ON 25 READINGS

FIG. 11

FIG. 12
CLEAVAGE MAP



also be applied to the Schmidt net. Poisson's function states that

$$P_a = \sum_{x=a}^{\infty} e^{-N/K} \frac{(N/K)^x}{x!} \quad \text{where}$$

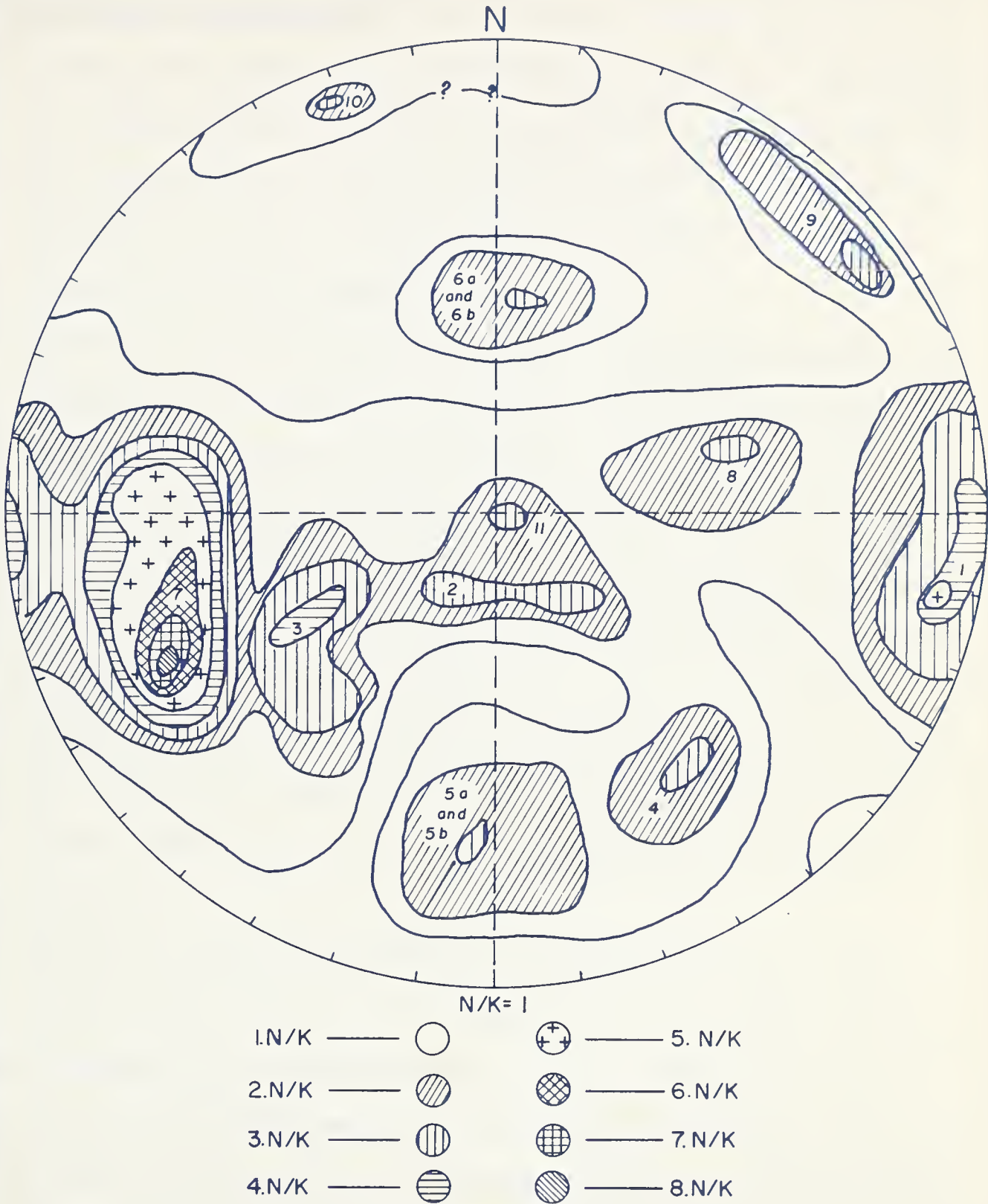
N is the total number of points on the net,

K the number of counting circles applied (N/K is thus equal to the average number of points per counting circle),

x the number of points in a particular circle, and

P_a the probability of a circle having greater than " a " points if the points are isotropic, where " a " = number of points, which if present in a circle, indicates unliklihood of isotropism. In using this function, standard Schmidt-net contours were drawn on x values and the contours re-evaluated in terms of equivalent N/K values. Since for this net, $N/K = 1$, x when equal to 1 is equivalent to N/K , and when equal to 2 is equivalent to $2N/K$, etc. To find the probability of isotropism represented by the cluster inside the contour in question, P_a was read against the various x (or equivalent N/K) values on the $N/K = 1$ curve in the frequency diagram of the Poisson series (based on Poisson's function) in Yule and Kendal (1950, p. 192). The smaller the P_a value the greater is the indication of anisotropism and a value of 0.05 is taken to represent mathematical probability of anisotropism. For the Schmidt-net under consideration (fig. 13), a probability of 0.05 corresponds to the $3N/K$ contour, and the plot is seen to be truly anisotropic. Eleven main joint-sets are thus indicated, of which 1, 3, 4, fracture cleavage (5b and 6b), 7 and 8, are, the commonest (Plate 5 A).

SCHMIDT DIAGRAM OF POLES TO JOINT-PLANES



150 FRACTURES
150 EQUAL AREA COUNTERS USED

FIG.13.

Description and Interpretation. The following interpretations of the origin and relative ages of the various joint-set (Table 1) were determined from their orientations as read from the Schmidt-net, their geometric relationships to each other and bedding, and field relations. These interpretations may not be the only ones possible, and indeed all joints may have several logical interpretations.

Joints in set 1 are present on both north- and south-dipping beds and are perpendicular to the regional structural trend. They are broadly and irregularly spaced, usually long and straight, commonly filled with vein material, and their planes, although most often smooth, may be rough where the joint has broken around grains in the rock. They probably formed during folding, possibly perpendicular to the minimum principal stress-axis and as extension joints (Billings 1956, p. 117). Later movement in the plane of the joints has caused some slickensiding and shear displacement. These joints cut and are cut by those belonging to all other sets and thus appear to have been formed throughout the entire period of deformation.

Since set 2 joints are approximately perpendicular to the south-dipping beds in which they occur and are cut by all other joints, they probably formed during an early stage of folding. They form a cluster on the Schmidt-net only because of the similarity in attitudes of the beds in which they were measured. Corresponding joints on north-dipping beds occur as gently south-dipping fractures, but were not plotted on the Schmidt-net due to a lack of sufficient measurements. Members of set 2, like those in set 1, are broadly and irregularly spaced, usually

SET	STRIKE	DIP	AGE	TYPE
1 ----	N.10°E. ---	80°W. --	Pre Folding to Post Folding ----	Extension
2 ----	N.90°W. ---	25°N. --	Pre Folding to Early Folding ---	Extension
3 ----	N.30°W. ---	40°NE. -	Early Folding -----	Shear
4 ----	N.55°E. ---	55°NW. -	Early Folding -----	Shear
5a ---	} N.5°E. ----	} 60°N. {	-- Late Folding -----	Shear
5b ---			-- Early Folding to Late Folding --	Shear
6a ---	} N.5°E. ----	} 40°S. {	-- Late Folding -----	Shear
6b ---			-- Early Folding to Late Folding --	Shear
7 ----	N.25°W. ---	65°E. --	Post Folding -----	Shear
8 ----	N.15°W. ---	40°W. --	Post Folding -----	Shear
9 ----	N.35°W. ---	80°SW. -	Post Folding -----	Extension
10 ---	N.70°W. ---	80°S. --	Post Folding -----	Extension
11 ---	Horizontal -----		Early Folding to Late Folding --	Tension

Attitudes of joint-sets, their ages relative to folding, and their genetic types.

Table 1

long and straight, commonly filled with vein material, and usually smooth. They vary considerably in strike, however, and it is not uncommon to see the extremes on the same outcrop. These may cross or curve together, with the center of the curve near the average orientation for the set. Set 2 is perpendicular to set 1 and may have formed contemporaneously, through gentle folding, with the early members of that set while the strata were nearly flat-lying. Pincus (ibid., p. 126) discusses a similar relationship of joints in northern New Jersey and Lahee (1952, p. 263) claims that it is very common for nearly flat-lying sediments to be intersected by vertical joint sets perpendicular to each other. On the other hand, set 2 could have formed through release of stress built up prior to or during an early stage of folding. No evidence of shear along these joints was found.

Joints in sets 3 and 4 are present in south-dipping beds only, are oblique to the regional structural trend, and form a cluster on the Schmidt-net only because of the similarity in attitudes of the beds in which they were measured. They are nearly always long and straight, and usually contain vein material which is often slickensided. Since these joints usually shear those of set 2 (Plate 5 B) but rarely displace those of set 1, they may have formed later than set 2 and contemporaneously with many joints in set 1. When the beds in which they occur are rotated into the horizontal, set 3 strikes north 50 degrees west, set 4 north 70 degrees east, and both are approximately vertical. The direction of displacement along them suggests that the related maximum principal stress-axis was parallel to their acute bisectrix (north 80 degrees west). This is per-

pendicular to the maximum principal stress-axis (north 10 degrees east) as indicated by set 1 and flow-cleavage. These sets are probably wrench-type shears that formed through local re-orientation of the stress-axes during an early stage of folding and are thus similar to those described by de Sitter (1957, p. 125). In north-dipping beds three joints of similar origin were measured, but not plotted on the Schmidt-net.

Sets 5 and 6 each consist of two genetically different sets which have similar orientations, 5a, 5b, 6a, and 6b. Joints of sets 5a and 6a are present in small numbers in both north- and south-dipping beds and though they are parallel to the regional structural trend the dips are independent of bedding. They are usually long and straight but may have a rough plane, and are not commonly filled with vein material. These joints displace, and are thus later than, the other joints discussed so far except for a number of set 1 joints. Their symmetry suggests they have undergone little or no rotation by folding. Their acute bisectrix is nearly horizontal and parallel to the set 1 extension joints and to the regional maximum principal stress-axis. They are thrust-type shears and probably formed during a late stage in folding when the dip of the beds was close to its present value.

Joints in sets 5b and 6b are present in south- and north-dipping beds respectively. They parallel the strike of the beds in which they occur but dip in the opposite direction. The joints are spaced only a few inches apart, are usually short, may be irregular, and rarely contain vein material (Plate 5 C). There is frequently minor displacement along them such that the upper block has been thrust over the lower (Plate 5 D)

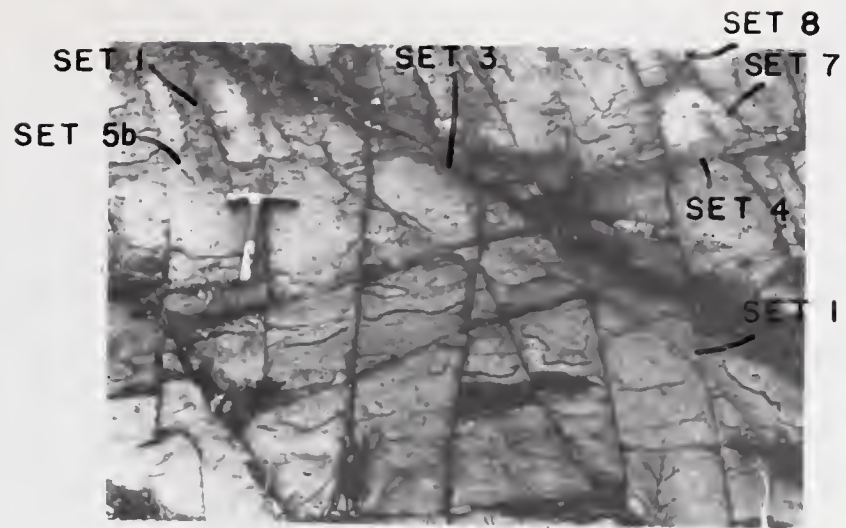
but due to the small displacement it is often hard to tell if they cut the other sets described so far. When the other sets are veined, however, the relationship is more apparent and members of sets 5b and 6b are frequently seen to be later, but probably were forming throughout folding. They are fracture-cleavage and, as can be seen in figure 14, increase in dip with increasing dip of the beds, but in the opposite direction. This particular type of fracture-cleavage may have originated at angles of not less than 30 degrees while the folds were gentle. As folding continued and the beds became steeper, the fracture-cleavage, rather than becoming shallower by rotation, became steeper by the deformation of the block cut out between the bedding plane and the fracture-cleavage (fig. 15).

Sets 7 and 8 form a conjugate system and are associated with set 9. They are long, straight, often filled with vein material and not infrequently slickensided. Either set may displace the other, suggesting they formed contemporaneously. Since they often displace all other sets, are never themselves displaced except by some set 1 joints, and are independent of bedding, they may have formed during a late stage of deformation. The direction of displacement along these shears suggests that the maximum principal stress-axis during their formation was plunging 80 degrees with a bearing of south 65 degrees west, while the intermediate principal stress-axis was horizontal and striking about north 25 degrees west.

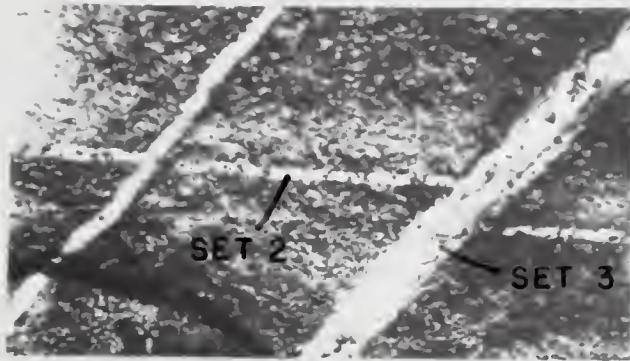
Set 9 which is usually veined, is independent of bedding and members are often associated with set 7 as feather-joints (Plate 5 E). Although little is known about this set, its relation to set 7 suggests it may have formed by extension in the northeast-southwest direction contemporaneously with sets 7 and 8.

PLATE 5

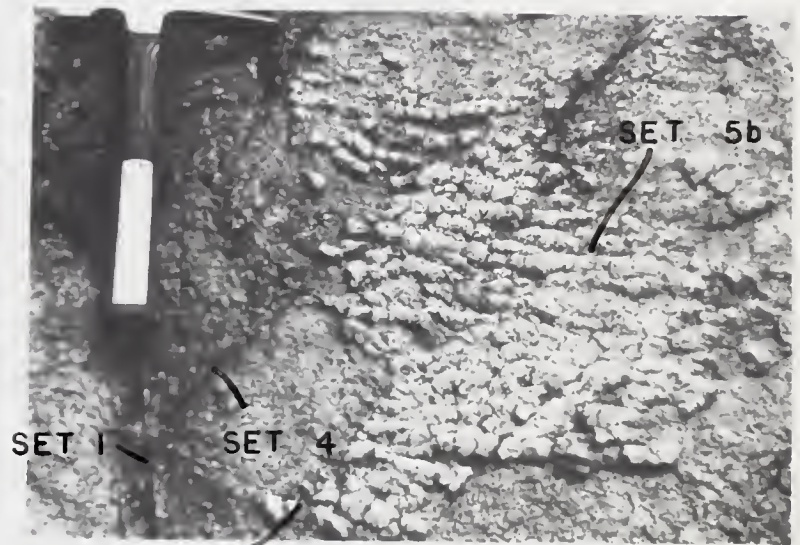
- A. Photograph looking north at the top of a south-dipping bed containing joints from sets 1, 3, 4, 5a, 5b, 7 and 8. Bed is in arenaceous unit number 12, 25 feet west of road.
- B. Photograph looking south at the bottom of a south-dipping bed in which veined set 3 joints displace a veined set 2 joint. Bed is in arenaceous unit number 7, 20 feet south of Whistlers Mountain trail.
- C. Photograph looking north at the top of a south-dipping bed containing joints in sets 1, 3, 4 and fracture cleavage set 5b. Bed is in arenaceous unit number 9, 200 yards east of the Miette River.
- D. Photograph looking west on south-dipping beds and at a set 1 joint plane. Here, joints in set 5b displace joints in set 3. Beds are in arenaceous unit number 12, 20 feet west of the road.
- E. Photograph looking north at the top of a south-dipping bed in which a veined set 7 joint, with veined feather-joints (set 9) is cut by an unveined (set 1) joint, and a veined set 1 joint is displaced by a veined set 3 joint. Bed is in arenaceous unit number 9, 50 yards east of the Miette River.



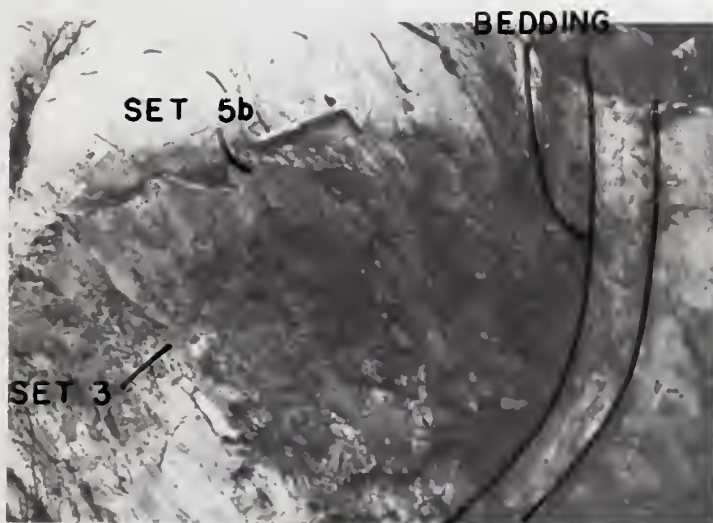
A



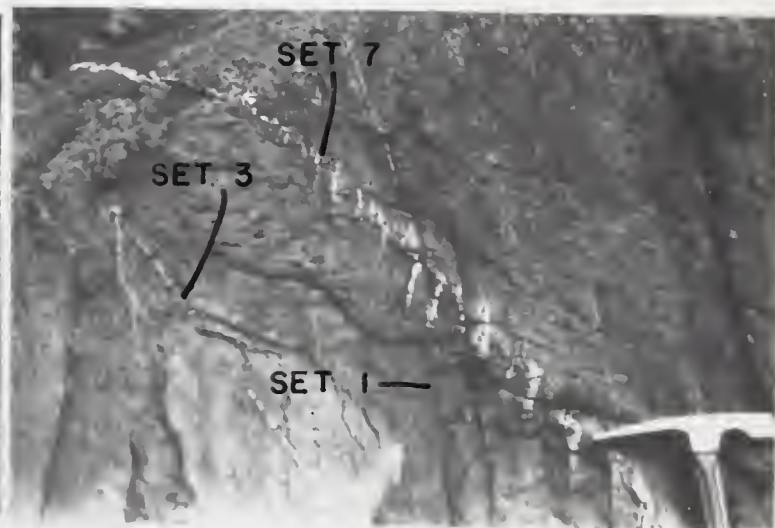
B



C



D



E

8 T32

7 T32

4 T32

3 T32

46

1 T32

25 T32

PLATE 5

1 T32

A. Photograph looking north at the top of a south-dipping bed containing joints from sets 1, 3, 4, 5a, 5b, 7 and 8. Bed is in arenaceous unit number 12, 25 feet west of road.

B. Photograph looking south at the bottom of a south-dipping bed in which veined set 3 joints displace a veined set 2 joint. Bed is in arenaceous unit number 7, 20 feet south of Whistlers Mountain trail.

25 T32

C. Photograph looking north at the top of a south-dipping bed containing joints in sets 1, 3, 4 and fracture cleavage set 5b. Bed is in arenaceous unit number 9, 200 yards east of the Miette River.

3 T32

4 T32

1 T32

3 T32

D. Photograph looking west on south-dipping beds and at a set 1 joint plane. Here, joints in set 5b displace joints in set 3. Beds are in arenaceous unit number 12, 20 feet west of the road.

BEDDING

7 T32

3 T32

25 T32

E. Photograph looking north at the top of a south-dipping bed in which a veined set 7 joint with veined feather-joints (set 9) is cut by an unveined (set 1) joint, and a veined set 1 joint is displaced by a veined set 3 joint. Bed is in arenaceous unit number 9, 50 yards east of the Miette River.

1 T32

3 T32



A



B



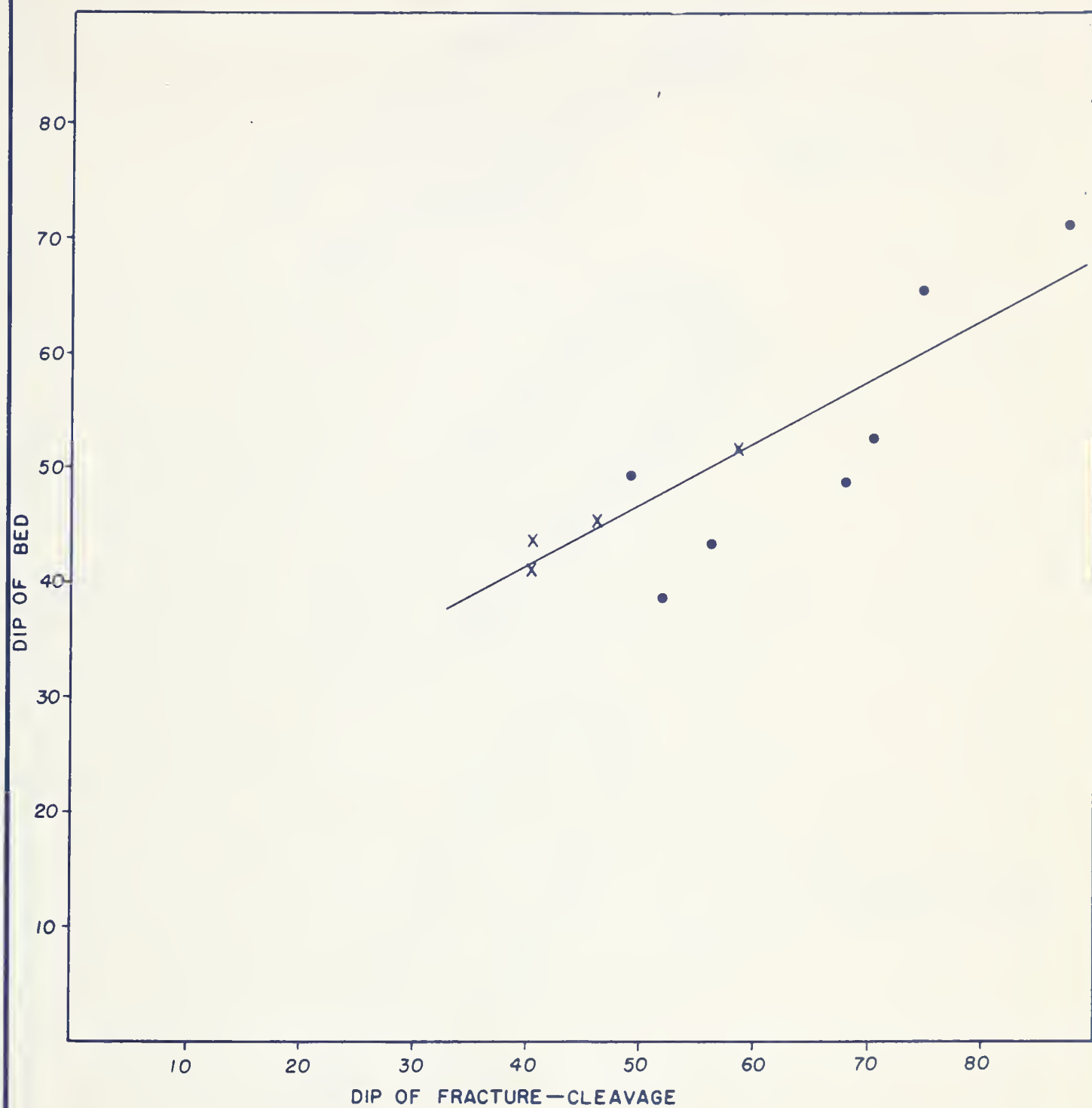
C



D

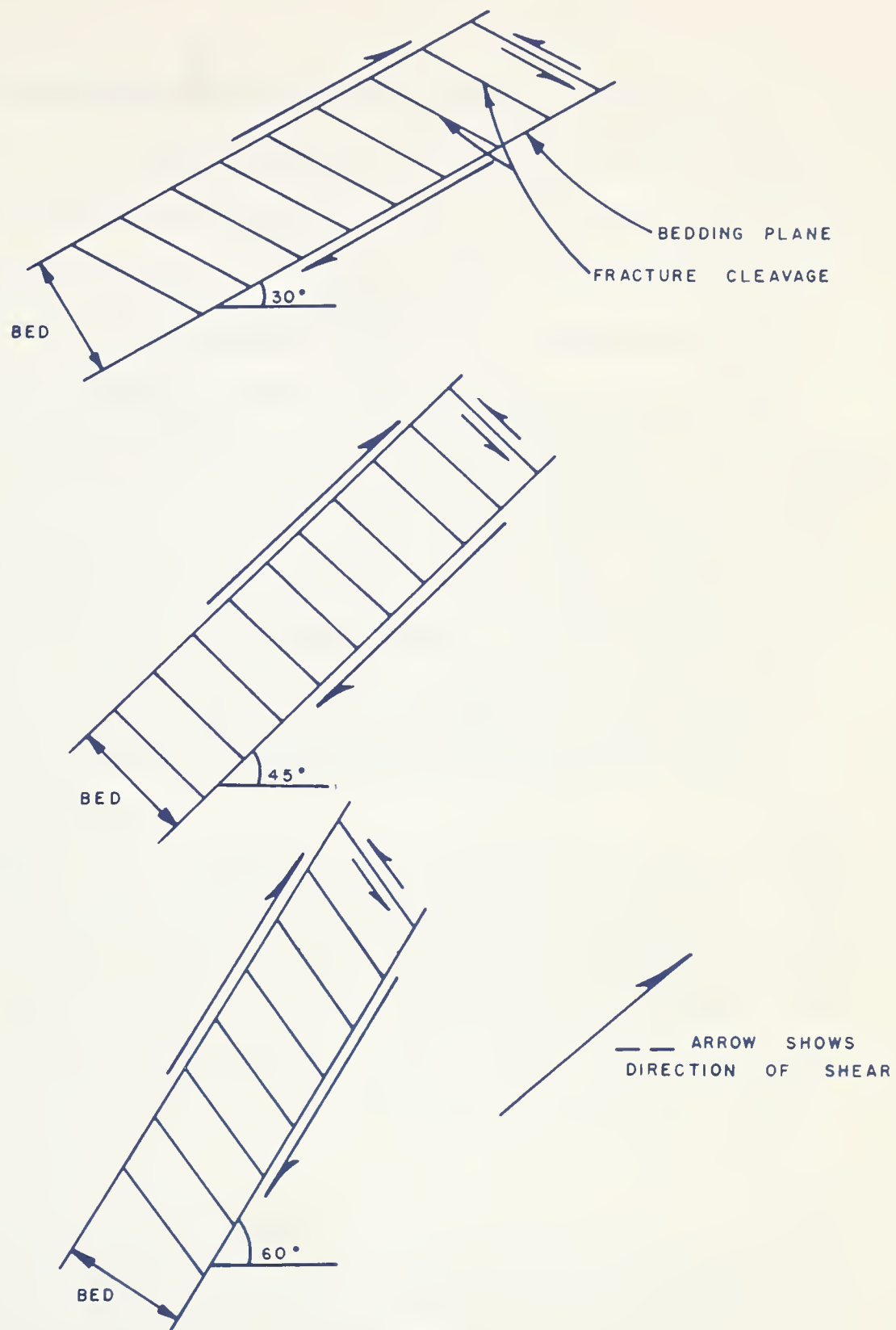


E



DIP OF FRACTURE-CLEAVAGE vs DIP OF BED

FIG. 14.



RELATION BETWEEN FRACTURE CLEAVAGE AND BEDDING-PLANE SLIPPAGE. AS FOLDING CONTINUES THE BLOCK CUT OUT BETWEEN THEM DEFORMS.

Set 10 is nearly perpendicular to set 9 and also independent of bedding. Like set 9 its members are generally small and usually veined. Although its relative age is not known directly, its relation and similarity to set 9 suggests they may be associated, with set 10 having formed by extension in the northwest-southeast direction. Joint-sets 7 to 10 seem to be related and probably formed within the normal fault stress-field during a late stage of deformation and almost certainly after folding.

The range in attitude of set 11 overlaps that of set 2 but its joints are easily distinguished as they are usually short, thick, irregular, vein-filled gashes and often occur in irregular groups. The relative age of this set is uncertain but it seems to have formed by vertical tension throughout most of the period of deformation and particularly during the final stages of folding.

There are several large, highly irregular fractures of unknown origin and age which are approximately parallel to bedding and vertical to steeply north dipping. Individuals may be nearly 100 feet long and contain a vast network of vein material, often swelling to over 2 feet wide and sometimes pinching down to only 1 inch wide. They cut and are cut by other joints in their immediate vicinities.

Bedding-plane slippage, although occurring in the argillaceous units, where it often cuts cleavage, is much more common in the arenaceous units and may best be seen along the road and railroad cuts. The slickensides represent movement during the last stage in folding only, as previous slickensides will have been destroyed by the later movements. Horizontal feather-joints, possibly members of set 11, are not uncommonly associated

with the slippage. There are also a number of apparently randomly oriented, slickensided planes which appear to be a result of differential slippage along individual bedding-planes.

Regional Plunge

In this area regional plunge may be found from the intersection of cleavage and bedding, the rake of bedding-plane slickensides, and the dip of extension-joints associated with folding (set 1). The average strike of the beds is parallel to the north 80 degrees west set of cleavage, thus no regional plunge is indicated (the north 65 degrees west set of cleavage, cannot be used to indicate regional plunge as it is related only to the oblique minor-fold set and not to the area as a whole). An analysis of the rake of bedding-plane slickensides may indicate a regional plunge if it is assumed that movement was perpendicular to the fold-axis. Assuming the fold to have a vertical axial plane, the relation between the rake, which is 75 degrees to the west (average of eight readings taken away from any minor folds), and the bedding, which strikes north 80 degrees west and dips 65 degrees south (average for south-dipping beds), indicates that the plunge is 33 degrees with a bearing of south 55 degrees east. The extension-joints, which strike north 10 degrees east and dip 80 degrees west (statistical average), indicate a plunge of 10 degrees with a bearing of south 80 degrees east.

There is large apparent discrepancy in the values for the regional plunge obtained by the last two methods. If the bearing of plunge as obtained by the rake-of-slickensiding method is taken as the correct

bearing then the plunge value as obtained from the extension-joint method is an apparent plunge only and the true plunge indicated by this method can be obtained from the formula,

$$\tan "t" = \frac{\tan "a"}{\sin "d"}^1$$

where "t" is the true plunge,

"a" the apparent plunge, and

"d" the angle between the bearing of the true and apparent plunge.

Substituting 10 degrees for "a" (plunge as determined from the extension-joint method) and 25 degrees for "d" (80 degrees minus 55 degrees), "t" is found to be 24 degrees. The plunge is thus 24 degrees with a bearing of south 55 degrees east, using the extension-joint method for first finding apparent plunge, and 33 degrees with a bearing of south 55 degrees east using the rake-of-slickensiding method. The discrepancy in plunge is thus only 9 degrees and can probably be explained by lack of a statistical number of rake measurements, or that one or more of the above assumptions is incorrect.

Since the bedding-cleavage relations do not indicate a plunge the cleavage may have formed before the plunge developed.

¹

This formula is an adaption of the formula on page 443 in Billings, 1956, for the calculation of true dips.

METAMORPHISM

Introduction. The rocks in the Ski-Lodge Road map-area are in the quartz-albite-muscovite-chlorite subfacies of the greenschist metamorphic facies (Turner and Verhoogan, 1960, p. 531). Two mineral assemblages are present: that of the rocks, and that of the vein material which fills many of the joints. The rock contains more mineral species than do the veins: those common to both were probably stable during metamorphism while the remainder in the rock were either stable, metastable, or unstable, depending on the mineral.

Veins. Although variation in the mineralogy of the vein filling of a joint-set may be considerable, differences between the various joint-sets appear to be slight. The vein assemblage is quartz-calcite-chlorite-albite, as shown on an A-C-F diagram (fig. 16), with an average composition of about 80 per cent quartz, 10 per cent chlorite, 10 per cent calcite, and 1 per cent albite. Some veins are monomineralic and composed of one of the three major vein constituents. The chlorite and calcite, though usually scattered throughout the vein, are often in pods, together or singly (Plate 6 A).

The quartz is usually elongate, with the c-axis either parallel or perpendicular to the wall of the joint. The direction of elongation is not always consistent with the nature of the joint, though the quartz appears to be perpendicular to the walls of set 11 joints, thought to be tensional (Plate 6 B), and parallel to the walls of set 3 joints possibly of shear origin. Strained quartz is common, especially where small

fractures or veinlets cut the material (Plate 6 C and D). Most quartz grains contain rows of globular and dusty inclusions but no mineral inclusions.

Calcite occurs as twinned crystals up to 1 inch in diameter (Plate 6 E). Some twin lamellae are slightly darker than the others, under the microscope, but it is not certain if these represent any compositional difference. The results of an X-ray diffraction method (see Goldschmidt and Graf, 1958, p. 97) indicate 2 per cent mole weight of Mg^{2+} in the calcite.

The chlorite has a distinct pale blue birefringence, is optically negative, vermicular in habit (Plate 6 F), and is not pleochroic. The results of an X-ray diffraction method suggested by Shirozu (1958, p. 223) indicate the chlorite to be monoclinic with a formula of $(Mg, Fe)_{4.6}(Fe, Al)_{1.4}(Al_{1.4}Si_{2.6})O_{10}(OH)_8$ with a Mg^{2+}/Fe^{2+} ratio of 3.6/1. Some chlorite has formed as an alteration of the vein feldspar.

Albite is scattered throughout the veins and occurs in small, albite-twinned crystals. The extinction angle of the twin lamellae indicate a composition of An_{0-15} , similar to that of feldspar in the rock (p. 18).

The presence of strained quartz, fractures, and veinlets of quartz, calcite, and chlorite in the veins suggest that there may have been more than one period of veining and perhaps that some post-veining deformation occurred. Other evidence of post-veining deformation is that unveined bedding-plane slippage and unveined joints often cut and displace veined joints (Plate 6 G; Plate 5 E).

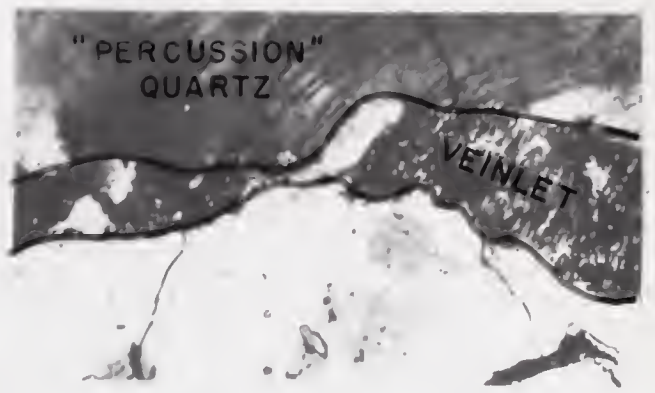
Rock Assemblage. As discussed on p. 17 the mineralogical composition of the rock is quartz-calcite-siderite-albite-chlorite-muscovite-biotite-

PLATE 6

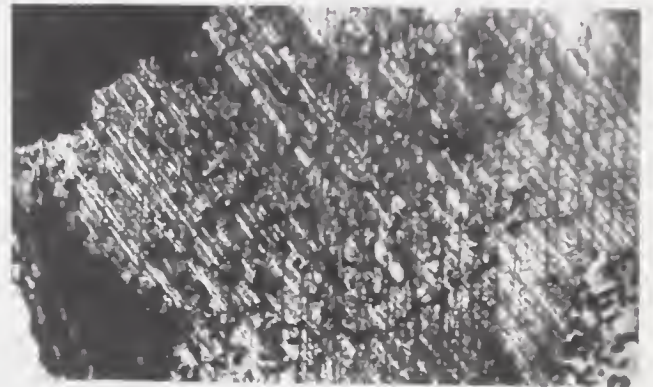
- A. Vein material filling a set 1 joint and consisting of quartz with a pod of calcite and chlorite. Joints are in arenaceous unit number 7, 25 yards east of the Miette River.
- B. Photograph of the vein filling of a set 11 joint, showing the elongation of quartz perpendicular to the joint wall. (30X, crossed-nicols). Vein is in arenaceous unit number 3, 10 feet east of the railroad.
- C. Strained quartz in the vein filling of a set 3 joint. (50X, crossed-nicols). Joint is in arenaceous unit number 12, 10 feet west of railroad.
- D. Strained quartz in the vein filling of a set 1 joint. (50X, crossed-nicols). Joint is in arenaceous unit number 9, 25 yards east of the Miette River.
- E. Twinned calcite and small, vermicular, chlorite grains in the vein filling of a set 3 joint. (50X, crossed-nicols). Joints are in arenaceous unit number 14, 20 feet east of the road.
- F. Vermicular chlorite and quartz in the vein filling of a set 7 joint. (50X, crossed-nicols). Joint is in set 9, 50 yards east of the Miette River.
- G. A field photograph showing unveined bedding-plane slippage displacing a veined set 1 joint. Some later vein filling of both bedding slippage planes and set 1 joints has occurred. Bed is in arenaceous unit number 7, 100 feet west of the railroad.



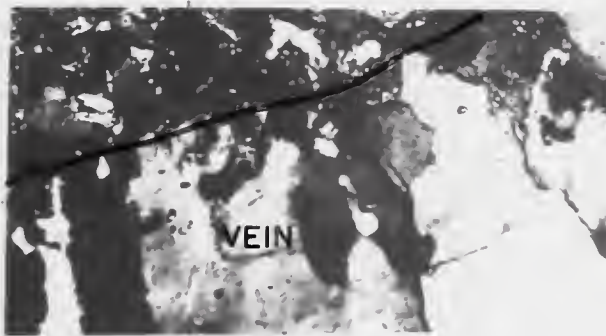
A



D



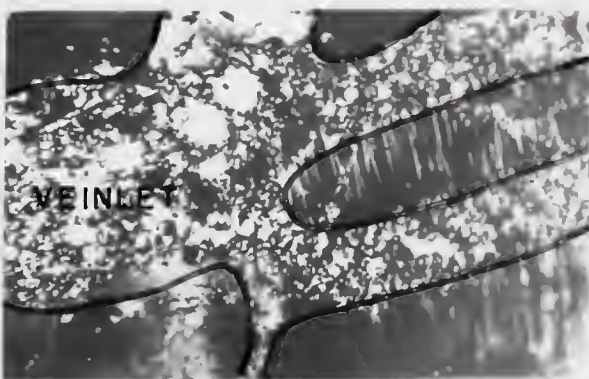
E



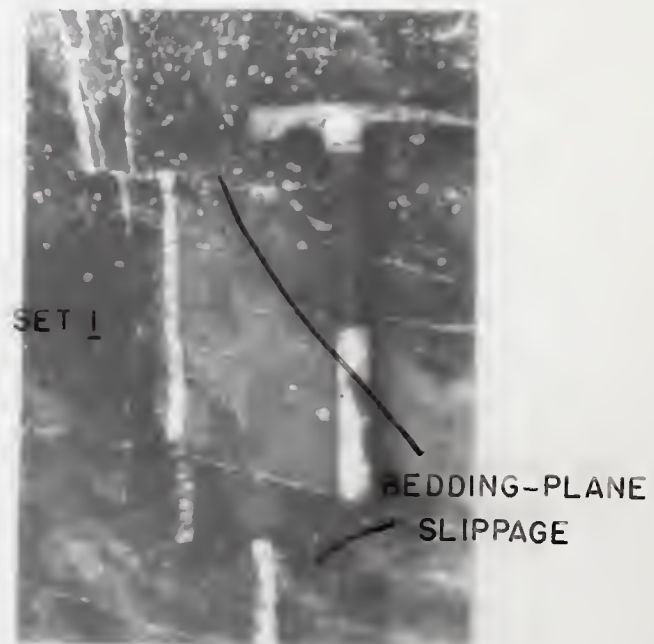
B



F



C



G

VEINLET

- A. Vein material filling a set 1 joint and consisting of quartz with a pod of calcite and chlorite. Joints are in arenaceous unit number 7, 25 yards east of the Miette River.
- B. Photograph of the vein filling of a set 11 joint, showing the elongation of quartz perpendicular to the joint wall. (30X, crossed-nicols). Vein is in arenaceous unit number 3, 10 feet east of the railroad.
- C. Strained quartz in the vein filling of a set 3 joint. (50X, crossed-nicols). Joint is in arenaceous unit number 12, 10 feet west of railroad.
- D. Strained quartz in the vein filling of a set 1 joint. (50X, crossed-nicols). Joint is in arenaceous unit number 9, 25 yards east of the Miette River.
- E. Twinned calcite and small, vermicular, chlorite grains in the vein filling of a set 3 joint. (50X, crossed-nicols). Joints are in arenaceous unit number 14, 20 feet east of the road.
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- G. A field photograph showing unveined bedding-plane slippage displacing a veined set 1 joint. Some later vein filling of both bedding slippage planes and set 1 joints has occurred. Bed is in arenaceous unit number 7, 100 feet west of the railroad.

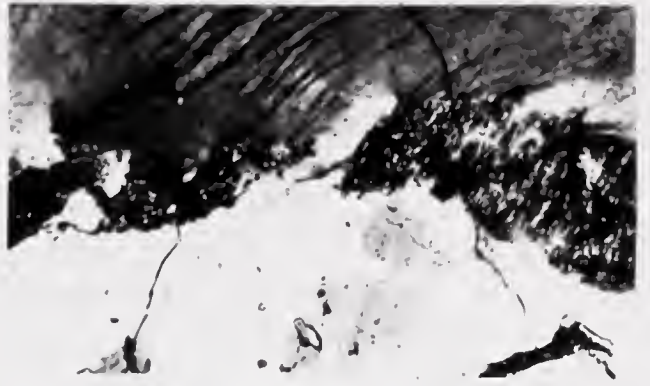
VEIN

VEINLET

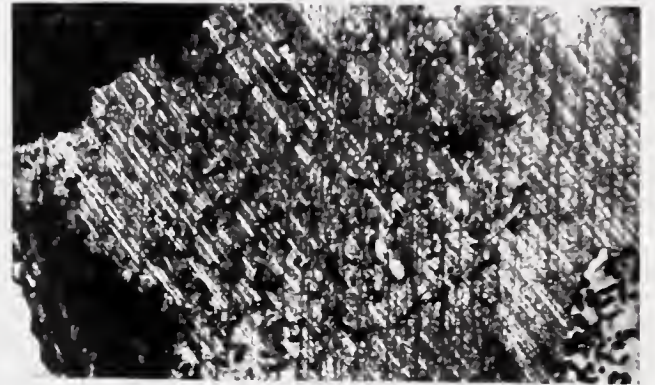
SLIPPAGE
BEDDING-PLANE



A



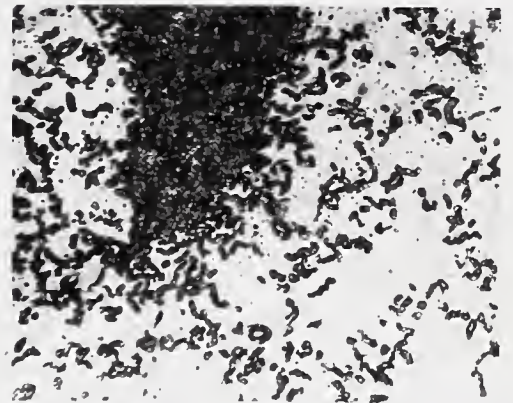
D



E



B



F



C



G

pyrite-ilmenite-magnetite-zircon-tourmaline-apatite-rutile. Some members of this assemblage were stable during metamorphism while others were not. Quartz, calcite, and chlorite, being present in the veins, undoubtedly were stable.

Albitization of the feldspar was an important metamorphic process and probably the replaced K^+ and Ca^+ of the original feldspars went to form muscovite and calcite respectively. X-ray diffraction results, using the method suggested by Smith and Yoder (1956, p. 641), indicate that the feldspar is a low temperature variety. The $\bar{2}01$ reflection has a double peak, one peak indicates an Or content of 6 mole per cent and the other, 0 mole per cent (see Orville, 1958, p. 208). This is taken to mean that two distinct phases of feldspar are present, one which is pure albite and the other which is transitional between pure albite and orthoclase. Completely albitized feldspar was probably stable during metamorphism while the rest was unstable.

Biotite is altered to muscovite and chlorite (p. 19) thus was probably unstable during metamorphism while both chlorite and muscovite were stable. Chlorite and muscovite have also formed by recrystallization of clay material (p. 22). Siderite occurs in well defined rhombs and thus appears to have been stable.

Heavy accessory minerals do not have regrowths associated with them and thus were probably metastable during both diagenesis and metamorphism. There appears to have been no alteration of the pyrite during metamorphism and it may have been either stable or metastable. The stable assemblage, quartz-calcite-siderite-muscovite-chlorite-albite-pyrite? is shown on an A-C-F diagram (fig. 17).

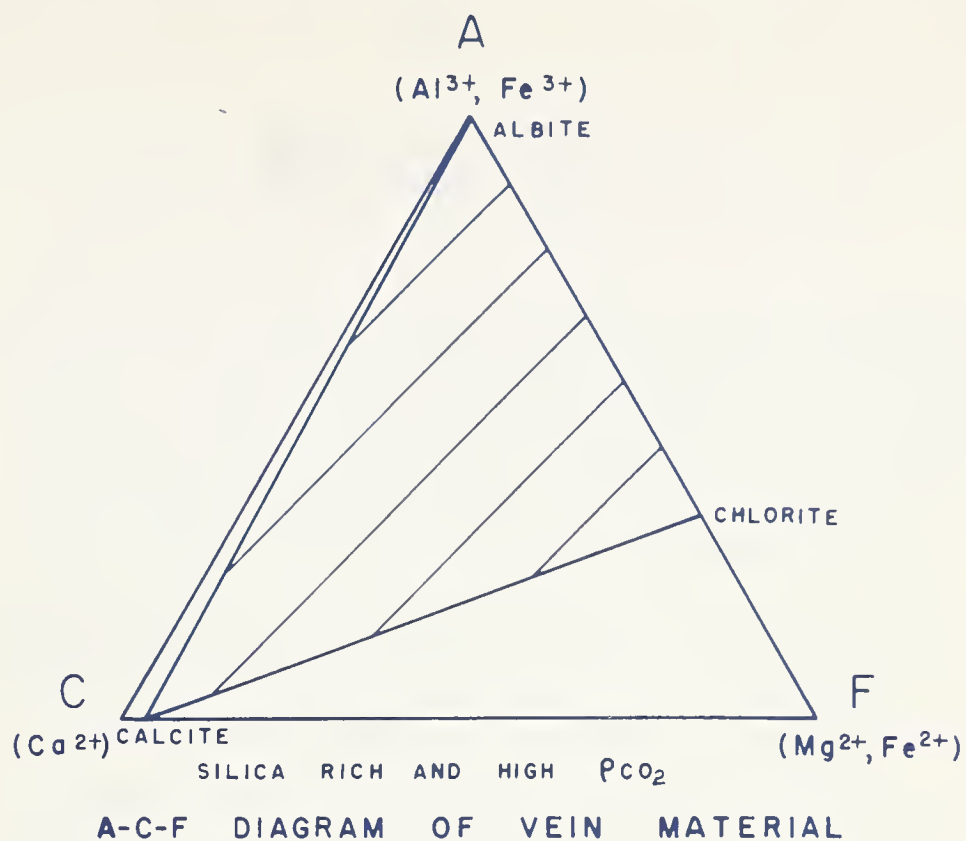


FIG. 16

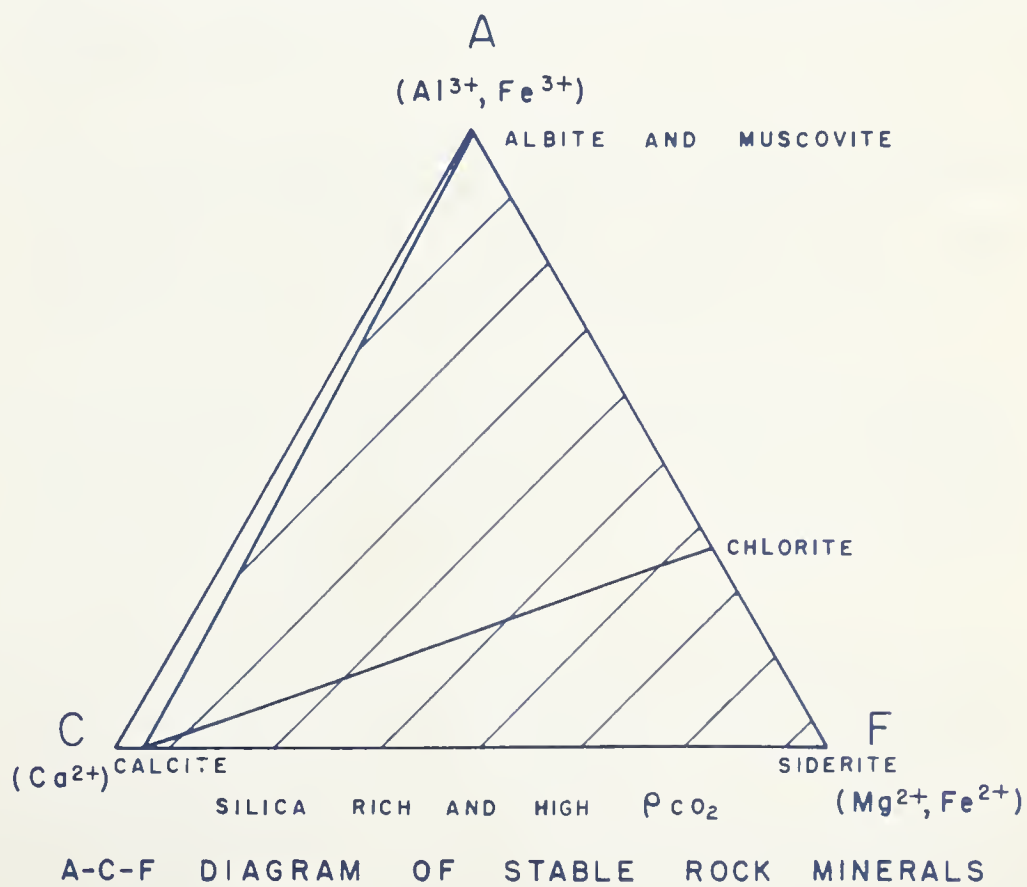


FIG. 17

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APPENDIX A

AGE OF THE SOURCE AREA OF THE MIETTE ROCKS

General:

An attempt to determine the geological age of the source area was made using the lead-alpha method to date detrital zircon. The age obtained, 1330 ± 150 million years, is considered to represent partial up-dating, through continual radon loss, of older material, rather than the actual age of the source area. The age determination was done by the United States Geological Survey, Geochemistry and Petrology Branch.

Preparation of Sample:

Approximately sixty pounds of fine-grained greywacke from scattered localities was crushed and sieved. Only the 80-120 mesh size range was retained for further separation as it was found to contain the highest proportion of zircons. The greywacke, being well indurated, caused considerable grinding of the rotary crusher plates with the result that the sieved sample contained many iron filings. These were easily removed with a strong hand magnet. Tetrabromoethane was used to separate out the heavy minerals and the resulting concentration was run several times through an isodynamic separator, set at increasingly higher amperages, to remove chlorite and magnetite. This enrichment was further concentrated by separation in methyl iodide and then hand picked to obtain, as nearly as possible, a pure zircon sample. Sixty-nine and one half milligrams of zircon, consisting of 90% malacons and dark hyacinths, 5% pale hyacinths, and 5% clear zircons, was obtained and sent for an age determination.

Meaning of the age determined:

The source area for the Miette rocks is believed to have been within the Canadian Shield (see page 32) and probably within the Churchill province. The Churchill province is considered to have been stabilized about 2000 million years ago, thus the lead-alpha date of 1330 million years represents an up-dating of 33.5%. Two possibilities exist: either the up-dating occurred through partial zircon recrystallization during diagenesis and/or deformation, or by radon loss since formation of the zircons (radon loss in the U^{238} to Pb^{206} decay system results in less Pb^{206} being formed thus reducing the age obtained when this system is used directly in the age determination). The former is not thought likely as there is no evidence of zircon recrystallization. Kulp (1955, page 613) says that radon leakage cannot occur through a crystal lattice but requires the presence of micro-fractures. The zircons in the Miette rocks are highly fractured (see page 23) thus facilitating radon leakage, and have undergone a long history of radioactive bombardment (see page 23). Radon leakage as the mechanism of up-dating is thus indicated.

The rate of radon leakage or diffusion is temperature dependent and increases exponentially with temperature. Although leakage has probably been occurring ever since formation of the zircon in the original crystalline rocks it must have increased during any subsequent metamorphism of the rocks containing the zircon. The age determined is thus also affected by tectonic events and an increase in rate of up-dating may have occurred during the Laramide orogeny.

Though the sample used for age determination was small and the method used relatively crude, the age obtained is in agreement with that

expected from geological consideration of source and interpreted history of the sediments.

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